

**THE HOLY LIGHT: A STUDY OF NATURAL LIGHT IN HINDU
TEMPLES IN THE SOUTHERN REGION OF TAMILNADU, INDIA
(7TH CENTURY AD TO 17TH CENTURY AD)**

A Thesis

by

ANURADHA MUKHERJI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2001

Major Subject: Architecture

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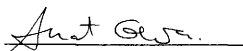
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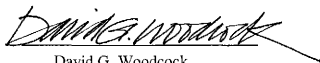
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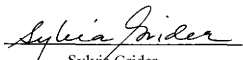
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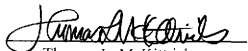
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ABSTRACT

The Holy Light: A Study of Natural Light in Hindu Temples in the Southern Region of Tamilnadu, India (7th Century AD to 17th Century AD). (August 2001)

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This thesis discusses the phenomenon of natural light that becomes the holy light in sacred architecture. In pursuing this investigation the study addressed three major objectives. First, to understand the significance of religion in the treatment of light in sacred monuments around the world. Second, to understand the methods used to achieve the desired light quality in the ancient south Indian Hindu temples. Third, to add to the existing body of knowledge in the field of study of ancient south Indian Hindu temples. Following these objectives the study developed two hypotheses on the basis of a literature review and a conceptual model. The first hypothesis says that the principles of religion govern the quality of light in sacred monuments. The second hypothesis suggests that accomplishment of light design technology is a function of time as expressed through building technology and building size.

To test these hypotheses and the conceptual model, this thesis studied the natural light systems in three Hindu temples built in the southern state of Tamilnadu in India. These three temple are the Shore temple built at Mahabalipuram by the Pallava dynasty (700 AD); the Brihadeshwara temple built at Tanjore by the Chola dynasty (1010 AD); and the Meenakshi-Sundareshwara temple built at Madurai by the Nayaka rulers (1660 AD). The study was conducted using multi-method analyses that included a qualitative analysis using accepted lighting design guidelines, and a quantitative analysis in the form of computerized daylight simulations.

The results of both the analyses show that though there are differences in the building size and techniques in each of the three Hindu temples, on the whole the

quality of light inside the structure did not undergo much change. Also though there was significant progress in the technology of lighting design from the 8th century to the 11th century, due to the changes in the political scenario, there was no further progress in this aspect of south Indian temple design from the 12th century AD onwards. The thesis concludes that the results support the paper's hypotheses and follow the Hindu religious requirement for light.

ACKNOWLEDGMENTS

I would like to express my gratitude to my committee chair, Dr. Anat Geva, for generously sharing her knowledge and expertise, and for her active guidance, support and encouragement throughout the period of my research.

In addition, I would like to thank Prof. David G. Woodcock for his valuable suggestions and comments. I am grateful to Dr. Sylvia Grider for agreeing to serve on my committee as a substitute member and for her meticulous attention to the details while reading this manuscript.

I am indebted to Dr. Lou Tassinary and Dr. Byoung-Suk Kweon for letting me use the resources in the Environmental Psychophysiology Laboratory. A big thank you to Kiran for his help during the computer modeling stage.

Lastly a special thanks to Toshi for all his love and support.

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INTRODUCTION

This thesis proposes to investigate how religious principles govern the treatment of light in sacred architecture, and how the development of building technology across time helped to achieve the religious light requirements. Specifically, this question is applied to the study of treatment of natural light in three Hindu temples that were built between the 7th century AD and 17th century AD. in Tamilnadu, India. In pursuing this investigation the study addresses three major objectives. First, to understand the significance of religion in the treatment of light in sacred monuments. Second, to understand the methods and technology used to achieve the desired light quality in the ancient south Indian Hindu temples. Third, to add to the existing body of knowledge in the field of study of ancient Hindu temples, in south India.

Since there has been not much research regarding the quality of light in Hindu temples, this study may serve as a reference for architects and designers in order to understand and preserve the importance of light in Hindu temples of south India. Furthermore, since there has been no study that describes the relation between light treatment, building size, technology and faith, the research could contribute to the study of the history of sacred architecture.

The thesis is divided mainly into six sections, which includes: Introduction; Literature Review; Conceptual Model and Hypothesis; Method; Results; Summary and Conclusion.

The Literature Review covers three major topics. First, Light and light quality in sacred spaces, where it summarizes various studies on light and the role of light in sacred structures in the context of their historical period. Second, Hindu temple layout and light, gives a brief description of the layout of Hindu temples and summarizes various studies describing light in Hindu temples. Third, Principles of lighting design,

summarizes Lechner's (1991, 2000) lighting design guidelines which are accepted as contemporary lighting design standards.

The Conceptual Model and Hypothesis as suggested by the title describes the conceptual model and the hypotheses of the study.

The Method covers three major sections. First, Study sample, where it describes each one of the three Hindu temples being studied. Second, Research instruments, where it describes Lechner's (1991, 2000) lighting design guidelines which would be used for the qualitative analysis along with a description of the lighting simulation software (Lightscape) which would be used in the quantitative analysis. Third, Procedure describes the criteria for the qualitative analysis along with the lighting simulation process for the quantitative analysis.

The Results section presents the results of both the qualitative (morphological) and the quantitative (lighting simulation) analyses.

The Summary and Conclusion section summarizes and discusses the results.

LITERATURE REVIEW

The literature review will cover three major topics: (a) Light and light quality in sacred spaces; (b) Hindu temple layout and light (c) Principles of lighting design.

Light and Light Quality in Sacred Spaces

Throughout time sacred monuments have provided spaces to facilitate a dialogue between man and God. The simplicity and the functional character of the monuments as well as the deliberate arrangement of architectural elements helped to create a holy atmosphere through the manipulation of light. Techniques such as light reflected from the walls creating mysterious shadows, subdued light filtering through the openings, light used as a focal point, etc. were some of the ways that natural light was used to represent itself as a fundamental connection to god. Thus, natural light was used as an important part of religious symbolism.

Though light has been such an important element in the design of sacred monuments, not much has been written on the subject. This literature review summarizes the few studies on the role of light in sacred structures in the context of their historical period. The summary focuses on two main aspects. First, the symbolism of light and its relation to the celestial body (Moore 1985; Plummer 1987; Mann 1993; Millet 1996). Second, a survey of the use of light in sacred buildings from the ancient till the modern time (MacDonald 1976; Grabar 1978; Grover 1980; Crouch 1985; Moore 1985; Plummer 1987; Mann 1993; Kostof 1995; Cruickshank 1996; Michel 1996; Millet 1996; Hart 1999; Russell 1999).

Moore (1985) has traced in brief the history of the use of daylight as symbolic and synonymous with heavenly light. According to his study, daylight as the primary source of light, has been the symbol of cleanliness, purity, knowledge, and heaven. Ancient architecture tended to admit light only where it was wanted. Windows and roof

openings were given special prominence within the structure and there were great changes in the light levels within a building. For example, in climates where daylight is plentiful and predictably bright, architects have responded by decreasing the opening size or using a diffusing medium in the openings (grilles, translucent or tinted glazing).

According to Plummer (1987), the earliest light deities were dynamic celestial bodies: the sun and moon, stars and planets. These sky gods occupied the vault of heaven, the starry region alive with cosmic powers. Even when not linked to the sun, luminescence was seen as an occupying power, a visitation, and an entry of the Godhead into otherwise dark and anemic material. While otherwise invisible, the divine spark could transfigure “profane” matter with its “sacred presence”. The impulse to “lure” and “build” light led to a legacy, of what may be the most intensely alive, man-made light worlds available today in temples and mosques, churches and abbeys, synagogues and shrines. Such concentrations of flaming matter continue to be as vibrantly entrancing as when they were built.

Mann’s (1993) discussion on the subject of light also emphasizes the cosmological and the astronomical connections between the sacred monuments and the celestial bodies. According to his study the geometric forms used by the Egyptians, Indians, Romans, Greeks and other ancient cultures have a profound mystical significance. The proportioning systems were used to understand the rhythms and the cycles of the sun and the moon, in addition to serving as a vehicle for meaning. This understanding was later incorporated into their sacred architecture, through various lighting techniques.

Millet (1996) has focussed on the divine aspects of natural light. He points out that light has long been connected with the spiritual aspects of life and with the forces that symbolize the sacred and the divine. Daylight becomes symbolic light when it is captured in a certain way. Symbolic light gains special meaning through association with that which is symbolized. Divine light in turn is a special aspect of symbolic light that represents the deity. According to Millet (1996), the sky provides the connection to divine light. He quotes Eliade (1958, p. 39), “Even before any religious values have

been set upon the sky it reveals its transcendence. The sky symbolizes transcendence, power and changelessness simply by being there. It exists because it is high, infinite, immovable, powerful.”

Symbolic light thus adds meaning that reaches beyond our visible world. Light can lead us beyond the finite and temporal, beyond our known experience in space and time. The divine itself is changeless, but the representation of the divine through light can be seen to change through time. Light is thus one of the many means of expressing the divine (Millet 1996).

According to Millet (1996), special meaning is accorded to light in all religions and the manipulation of the quality of light is interpreted in many different ways. The natural language of light and dark is a powerful one with which to express meaning in architecture. Light can reveal or suppress. Darkness is necessary to complete this experience of light and by suppressing visual perception, it represents the unknown, provoking many responses. Darkness as well as light is rich in associations and carries with it the potential for expressing meaning. Its effect can induce a mood, a feeling, or a state of mind. Physically, light affects the pineal gland in the middle of the brain, which in turn is connected to all our glandular, hence emotional, centers. It has the capacity to move us. Light symbolizes that which is beyond our normal comprehension. A sunrise, the colored mosaic of light moving across the surfaces of a Gothic cathedral, the darkness of a Nordic stave church, all convey a certain meaning to us which differs according to our momentary state of being. Millet (1996) concludes by quoting Eliade (1958, p. 450), “Light and darkness, for instance symbolizes at once the day and night of nature, the appearance and disappearance of any sort of form, death and resurrection, the creation and dissolution of the cosmos, the potential and the actual.”

In summary, the discussion of light and sacred architecture in the literature essentially reveals that light has long been connected with the spiritual aspects of life and with the forces that symbolize the sacred and the divine. The following discussion is dedicated to a brief history of the evolution of expression of the holy light, according to various authors (MacDonald 1976; Grabar 1978; Grover 1980; Crouch 1985; Moore

1985; Plummer 1987; Mann 1993; Kostof 1995; Cruickshank 1996; Michel 1996; Millet 1996; Hart 1999; Russell 1999) and my observations. Since this research focuses on south Indian sacred architecture, which had a very formal monumental structure, the following discussion would limit itself to the form of sacred monuments that were built as formal structures representing the ruling powers of that period. Although there is a deep symbolism and meaning in the vernacular forms of sacred architecture, this paper does not address this topic.

Crouch (1985) has examined light and its effect upon architecture through the study of sacred monuments from various historical periods. In a chronological order, Crouch (1985) has given a brief sketch of the use of light throughout western history, from the Egyptian temples to the Baroque churches.

In the prehistoric time the sacred aspect of temporal¹ change is expressed in special places such as Stonehenge, a unique megalithic monument on Salisbury plain in Wiltshire, England and the Mnajdra solar temple complex in Malta (Kostof 1995). The Stonehenge was designed and built in the third and second millennium BC. The complex is organized around the view of the rising sun at the summer solstice. This view created a focal point from the center over the heel stone. At other times of the year, other lighting effects relate the center to different stones at the edge, thus keeping track of the passage of time, of the sun's journey through the heavens (Crouch 1985). It is a solar-lunar observatory and temple. Being the sacred ceremonial center it may be seen as a sanctuary to the earth spirit penetrated by sun rays (Mann 1993).

The solar-lunar system symbolized life and death in Egyptian time, where life was conducted in the east (sunrise) and the valley of death was in the west (sunset). In ancient Egypt, the presence of harsh sunlight and glare minimized the size of openings which were also limited due to the structural spanning capability of the heavy stone blocks used for post-and-beam construction. In some large temples, light was

¹ Temporal change here means the change in time, the cycle of day and night as well as the change in seasonal cycles throughout the year, which brings a change in the quality of light. The light quality keeps changing along with the changes within these cycles of nature.

introduced to the interior through the clerestory openings that utilized the changes in roof levels. These openings were fitted with carved stone grilles to soften the light and shade the interior. In addition, light reached the interior through roof slits, small window openings and through entrance doors (Moore 1985). There are many aspects of the meaning of the Egyptian temples which go far beyond the mere appreciation of a geometrical form in the desert sun (Millet 1996). These temples made calculated use of light. The outer public spaces of the temple were large, open and full of light. The consecutive spaces gradually became lower, narrower, darker and more private until the innermost sanctum was the smallest and darkest (Crouch 1985). As each section of the temple was designed and built, the axis shifted, requiring a new alignment so that the rising sun would shine through the halls of the pillars to the shrine within (Mann 1993). In the Great Temple of Ammon the quantity of light was intentionally varied to reinforce the axial sequence through the great Hypostyle Hall and finally to the darkest inner sanctum (Moore 1985). One small opening in the darkest inner sanctum illuminated the sacred statue housed within, with focussed light. This treatment of light reinforced the importance of the holiest component of the temple.

The climate of Greece is mild, and many public activities were conducted outdoors in ancient times. The strong direct and reflected sunlight still sharply articulate the carved ornamentation on the column shafts, capitals, entablatures, and friezes of the Greek temples. The temples were usually oriented to the east to illuminate the golden statue of the deity through the doorways at sunrise, which would in turn emanate divine light from the sanctuary. Because of the relatively small opening spans, the interior of the temples would receive narrow shafts of direct sunlight at low sun angles in the morning and more diffuse skylight and reflected ground light during the remainder of the day (Moore 1985). For example, in the Parthenon, the statue of Athena was illuminated by three kinds of light. Direct light came from the large open doorway. Indirect light was reflected off the shallow pool at the foot of the statue, up to Athena's face. Finally a diffused light came through the translucent marble tiles of the roof (Crouch 1985).

This phenomenon of orienting the sacred monument towards the sun was universal. It happened in ancient China and Japan too (Mann 1993). According to the observations of the author,² the sacred shrines, temples and monasteries in the Far East did not allow any light to enter the innermost hall or sanctum. Their architecture followed similar principles as those of the ancient Egyptians, the innermost sacred chamber would remain in darkness at all times, though the outer galleries or surrounding halls would have many openings to filter the light in. Japanese author Tanizaki (1977), put it very simply, “were it not for shadows, there would be no beauty...”

The ancient Buddhist rock-cut cave and monuments were built more like twilight spaces where the eye could gradually discern the architecture inside the cave (Grover 1980). The Karli Chaitya Griha is a typical example of Buddhist cave temples, with its solemn and majestic central hall flanked by massive columns and the hemispherical Stupa as the focus. The cave had no openings except the main entrance and a sun window, which was built above the massive arched entrance. The hall, (45 x 150 ft.), receives soft luminous light from the entrance façade, filtered through the outer colonnade, the screens and the oriels of the sun window. The Stupa at the far end of the hall is aligned in a straight line with the entrance, and at certain times of the day it glows with the light, which falls on it from the entrance and the sun window. Similar to the Far East countries, there is no existing literature on the subject of treatment of light in the ancient Buddhist sacred monuments. The observations stated here are those of the author.

In ancient Rome, the development of the round arch, barrel vault, and dome allowed masonry materials to be used for large spans. These larger interiors free of columns created the potential for large wall openings that could admit great sheets of light in contrast to the Greeks (Moore 1985). In the Pantheon the bright stone-built open

² In the case of ancient China, Japan, Korea and the other far-east countries, there is no existing literature on the subject of treatment of light in the sacred monuments.

court gave way to the relatively dim porch, darker toward its farther reaches. Within the rotunda the lighting was reversed and became full and unimpeded (MacDonald 1976). The oculus in the dome controls the direction of a disk of light so that it directly strikes one altar in the morning and then moves gradually across the floor to shine on the opposite altar in the afternoon (Michel 1996). The long cylinder of light that is shaped by the oculus connects the individual with the heavens and bridges the tangible and the intangible (MacDonald 1976).

In Early Christian (313-800 AD) cosmology the universe was visualized as a chamber, a cubic box with the lid of the heavens surmounting it. The heavens were made of either metal or crystal, with holes to allow the celestial light to penetrate (Mann 1993). The basilica building type, used in ancient Rome as public meeting place, was adopted with little change for religious services. Timber trusses replaced the ancient Roman concrete vaulting, resulting in changes of roof levels that reduced the wall area available for clerestory windows. These clerestories, as well as side-aisle windows, became smaller in size and more numerous. The reduced illumination served to enhance the mystical nature of the new religious functions. The apse, containing the altar, was typically semicircular in plan and surrounded by windows that gave greater visual emphasis to this area and reinforced the linear perspective convergence toward the altar (Moore 1985). In the old St.Peter's and other basilicas, differences in the amount of light mark differences in the functions of various spaces within the church such as the nave and the apse (Crouch 1985).

The most distinguishing characteristic of Byzantine architecture (330-1453 AD) was the development of domed sacred structures. The Byzantine plan was centralized around a primary dome, surrounded by secondary spaces covered with half domes intersecting below the main dome. Light was admitted through many windows, piercing the base of the dome, creating the illusion of the dome floating above the supporting structure (Moore 1985). In the Byzantine church of Hagia Sophia 40 windows are pierced in a ring in the central dome providing broken patterns of light in addition to the light coming through the grilled windows that are cast onto the carved stone walls

(Millet 1996). The rays of light fall diagonally across the interior of the central domed spaces as gentle beams. From the full shade of the vestibule and galleries to the partial light of the aisles, one comes to the full light of the great central spaces (Crouch 1985). The walls seem to dissolve into limpid pools of light (Millet 1996).

In S. Marco (Venice, Italy), a combination of Medieval and Byzantine architecture, the light entered through and reflected from the gold and brightly colored mosaic, gives the aura of divine light within the church (Millet 1996).

In Islamic architecture, the light was beautifully taken in through openings with delicately carved grills. In Jerusalem, Byzantine craftsmen built the Dome of the Rock. This monument was a centrally planned octagonal martyrium with a double ambulatory and a dome which includes two wooden shells. The dome is lit by windows, which are set right below it in the drum. The openings reflect the daily cycles of light and darkness and the changing positions of constellations. As the source of the light, the sun or the moon, changes its location, different combinations of facets are illuminated, giving an illusion of rotation, a representation of fundamental rhythms of the universe, a rotating heavenly dome (Grabar 1978). In the great mosque at Cordoba, the arched lattice-works hold rather than instantly pass light. They insert glinting pools into the most solid fabric of the building, This infiltration of dense matter with light intensifies as outer apertures are lost from view, allowing the snagged rays to be seen as residing within and even emitted by the corporeal shell (Plummer 1987).

In the Islamic architecture of Moghul India (1100-1600 AD), the typical plan of a mosque was a central courtyard with cloisters on three sides and the Mihrab wall facing Mecca. The central section of the prayer hall would be topped by a dome structure and there would usually be openings, high up on the Mihrab wall, towards the dome. The prayer hall would have a central aisle with arcades parallel to the Kibla axis. In the Jami Mosque at Fatehpur Sikri, a window high up in the Mihrab wall symbolizes holy light from Mecca. The subdued light coming from this window gives the prayer hall a soft glow, while the carved geometric pattern on the window filters the light into

the prayer space. The quality of light from these intricate openings keeps changing throughout the day and in turn changes the atmosphere of the prayer space.

The Romanesque period (800-1100 AD) was characterized by a return to the round masonry vaults and arches of the Roman period. Due to the cold weather and risk of fire, the sacred buildings developed a double roof system of a wooden roof at the outer side and a masonry vault in the inner side of the roof. The linear Basilican church plan evolved into a long cross plan. Windows in the load-bearing side walls remained relatively small (with no glass) in Italy and southern France, becoming slightly larger in northern Europe where the non-bearing end walls could sustain larger openings (Moore 1985). The Romanesque churches thus tended to be dark (Crouch 1985).

The Gothic period (1100-1600 AD) elevated stone masonry to its highest level of structural sophistication. The development of the pointed arch and the flying buttress allowed the replacement of the bearing walls with columns and in turn led to larger openings. The development of stained glass reinforced the expression of divine light, in addition to narrating stories from the Bible visually through the medium of color and light. In the cathedral of Notre Dame de Chartres (1194-1220 AD) in France, the light was revealed through the medium of stained glass windows. Huge areas of glazing are interspersed with the delicate structural members so that the interior is bathed in light entering through the deep blue and red stained glass windows (Millet 1996). North light is quite cold, and therefore in the North Rose the colors red and blue are more predominant. By contrast, in the South Rose the light is warmer due to exposure and so the gold and white are more in evidence and provide a lighter and more dramatic effect (Mann 1993). It was believed that the light passing through the windows was transformed or transmuted, becoming representation of diving light, and therefore had a healing and revivifying effect upon the people gathered within the cathedral (Mann 1993).

During the Renaissance period (1400-1830 AD) the day-lighting techniques became more subtle, sophisticated and innovative. Daylight was typically used to emphasize architectural form and dramatize internal spaces. The thick walls required

deeply recessed daylight openings, often hidden from direct view. The domes were supported on “drums” which were pierced by large windows and surrounded by columns. Often in the double or triple shelled domes, the exterior and interior domes were separate structures, requiring a complex path for admitting daylight to the upper portion of the dome (Moore 1985). In the cathedral of S.Maria del Fiore in Florence, the lantern crowning the massive double shell dome allows the light from the sky to enter the oculus of the cathedral indirectly. Of the three shells, in St. Paul's Cathedral in London, the inner brick shell of the dome has an open oculus like the Pantheon looking through to the tall brick cone, where small openings are pierced, allowing light to penetrate (Cruickshank 1996). Unlike the Pantheon, the presence of the lantern and the multiple layers of the dome change the quality of light entering the cathedral.

In the Baroque period, light was one of the elements of architecture that were manipulated for emotional effect. At San Carlo alle Quattro Fontane in Rome, the facade is a series of projections and recessions, emphasized by the light and dark of both highlight and shadow. Both the interior and the exterior have ranges of visibility from things that are hard to see because they are in such brilliance, to the elements that are difficult to see due to the darkness (Crouch 1985).

In recent history of sacred architecture along with the religious requirements, the personal vision of the architect became a source of the symbolism of light. During the modern movement in the first half of the 20th century, some architects such as Frank Lloyd Wright, Le Corbusier, Alvar Aalto, retained many of the historical principles of site orientation, natural ventilation, and daylight illumination in the design of sacred spaces. An example of this is the chapel of Notre Dame de Haut at Ronchamp, France, where Le Corbusier has dealt with light as a building material. The interior is dim and mysterious and the openings are deeply baffled with the daylight filtering through the colored glass similar to the great cathedrals. The light from the small openings is made more apparent within the dark interior, and becomes the symbol of holy light (Millet 1996).

In the second half of the 20th century architects like Louis Kahn and Tadao Ando have used the qualities of natural light in an innovative manner. According to Louis Kahn, "...all material in nature, the mountains and the streams and the air and we, are made of Light which has been spent, and this crumpled mass called material casts a shadow, and the shadow belongs to light. So Light is the source of all being" (Lobell 1979, p. 22). In Church of Light in Japan, Tadao Ando uses architecture to unleash the spiritual power of light. The cross cut into the concrete wall seems lit from behind by a mysterious light. In spite of its modesty of size, nature appears in the form of light blazing through a cruciform slot situated behind the celebrant. The afire crucifix is a powerful expression in the use of daylight. The angled wall allows bands of light to move across the interior walls. The worshipper becomes aware not of the walls, but of the light and its movement as the day passes (Russell 1999).

Sacred light thus connects us with a higher order of things, with the essential, with the immutable truth. Sacred light is not tied to revelation of a particular deity, or to a particular religion, or even to a typical religious place, such as a church. Rather sacred light reminds one, whenever one comes into contact with it, that a higher order exists (Millet 1996).

Hindu Temple Layout and Light

Faith in ancient India meant more than holy tenets to be adhered to or a method to prevent citizens from straying. Rather than being a religion, Brahmanism, later known as Hinduism, was a gradual amalgamation of Aryan and Dravidian customs and traditions. God was everywhere, in every person and every object. As an all-pervasive force, he ruled in both subtle and obvious ways, the thought processes, the actions, the consequences and the beliefs of people's lives. In its essence, Hinduism is a way of worshipping life in its every form, and a path towards co-existence. It is believed that the temple was simply a concrete location given to god for the benefit of those who could not perceive him in the superior form of pilgrimage, the manastirtha (pilgrimage

of the mind). However, as religious architecture evolved, the shrine with all its inherent significance, became a symbol of power and wealth with dynasties vying against each other to create more magnificent, more memorable edifices, which eventually ended up serving only the privileged elite (Marathe 1998).

According to Michell (1987), the Hindu religion focuses highly on the temple and its rituals of worship. The Hindu temple was not only a monument providing shelter to the image and the worshippers, but was the cosmos itself. Starting from a cave, onto a hut or a modest abode of timber, the temple gradually evolved into a substantial structure embellished with decorative moldings and ornaments and meaningful sculpture (Deva 1995). The ancient scriptures and the religious beliefs dictated the architecture of the temples. The use of the square as the basic unit in Indian temple architecture was chiefly a matter of religious significance. The square was the mystical and absolute form, which did not permit any variation in the course of construction. The Indian architect was solely concerned with the religious significance of the grid he used and could not modify these basic geometric figures. As the centuries passed, he kept to the ancient forms and repeated them, using completely different materials. The ground plan of the temple was that of a square grid. Each of the squares was thought to be the abode of a deity, and the location of the square within the ground plan accorded with the importance attached to the deity. The square in the center of each building was the seat of Brahman³ (Volwahren 1969).

According to art historians, two major styles of Hindu temple architecture evolved in India from the 7th century AD onwards. In the northern region of India, temples were built mainly in the Indo-Aryan, or the nagara style (Volwahren 1969). The nagara temple is characterized by its square shikhara (the spire), which rises above the cubic sanctuary in the shape of a parabola. The other style of temple form developed mostly in Tamilnadu, anciently known as Dravidadesha, and thus referred to as the Dravida style (Brown 1968). The outstanding features of the Dravidian temple

³ One of the chief Indian gods, known as the creator of all living beings.

architecture are its two types of tower, the vimana and the gopuram. The vimana is square in plan and structure and has a rounded cupola as its finial whereas the gopuram is oblong and has an oblong vaulted roof (Volwahren 1969). In both styles the object of worship is usually housed in a small dark chamber, the garbhagriha (the womb chamber). The plan of the Hindu temple is based on geometric form and all the other parts of the temple are organized around this chamber. The sequences of porches and halls, normally aligned on an east-west axis, lead in a succession of spaces towards the object of worship (Michell 1987).

In its elaborated form the Hindu temple may include the following elements. "The central shrine, a dark chamber is called the garbhagriha or the house of the womb, germ or embryo. The stone statue or emblem of the main deity of the temple is in this innermost cell, and behind or beside this chamber there may be a second chamber to house the consort of the deity. Above the central shrine rises the main tower of the temple and it is called the shikhara (summit) and has a stupa (finial) on the top. The word vimana (well measured, well proportioned) is also applied to the tower above it, but is used also to designate both the central shrine and the tower above it or the entire temple itself. The door of the garbhagriha opens mostly to the east and into another rectangular chamber called the antarala or vestibule. This in turn opens into a pillared hall called the mandapa, which is where worshippers gather. Entrance to this hall is through a smaller pillared porch known as the ardhhamandapa or half mandapa. If there is a transept on either side of the central hall the whole is called a mahamandapa. An ambulatory passageway around the sanctuary is the pradakshinapath (processional path). Subsidiary buildings are the natmandir or hall of dancing, for the female temple dancers; the bhogmandir or hall of offerings; and shrines for associated lesser deities. An enclosing wall may surround large temples, and here there may be additional cells facing the temple. Furthermore, the temple is provided by a wealth of carvings both inside and outside, showing the lives of the gods and the people, making the entire structure a vast sculpture" (Finegan 1989, p. 176).

Sun the giver of light has been worshipped in Hindu India throughout the ancient times. According to the ancient Hindu scriptures, in the sphere of the sky the active principle is that of the sun, known as the god Surya. "He is the sun of the heaven and his name (Surya) is derived from the word svar (light). The Rigveda⁴ describes Surya as the golden ornament of the sky, a flying falcon, and the very countenance and eye of the gods. Traversing heaven and earth in a single day, Surya observes the whole world from on high. It is his work to dispel the dark night of ignorance and to dispense the light of life and health" (Finegan 1989, p. 37).

As written in Rigveda 1.50: "Like thieves yonder constellations stealthily depart with the nocturnal darkness before the all-beholding Surya. His signs, his beams are widely visible in the world, shining forth in splendor like fires that burn and blaze. Punctual, seen by all, you are the maker of light, O Surya; you illuminate all the radiant realm. You traverse the sky and the wide air, you measure the days with the nights, O Surya, you behold all the creatures. Looking upon the higher light above the darkness, we have come to Surya, the god of gods, the highest light" (Finegan 1989, p. 38).

In spite of the importance given to sun as the source of light, natural light was used very sparsely in the Hindu temples. Mainly the ancient scriptures and the religious beliefs dictated the architecture of the temples. The Hindu religious belief is that when man is in the presence of the divine, there should be nothing to distract his eye and that God shall reveal himself to his devotee gradually (Deva 1995). The ancient abodes of gods were typically in caves and on mountains. A structure of the temple resembles a cave, which the worshipper penetrates in order to approach the most holy place. Its vertical dimension is like a mountain, which suggests the ascent to enlightenment and deliverance (Volwahren 1969). The sanctum is customarily a dark chamber enclosed by massive walls. Flickering flames of oil lamp dimly light its somber interior. This suggests and simulates the mystery that envelops the universe and the divine spirit that shines behind the veil of mystery and pervades and illumines the universe. The sanctum

⁴ An ancient Hindu scripture composed of a set of hymns.

with its massive walls and the dark interior thus represents a cave, while the superstructure with its peak like spire represents a mountain (Deva 1995).

From the glare of sunshine, as one enters the temple, the experience is that of moving inwards through gradually darkening spaces and finally to the innermost sanctum, which is shrouded in total darkness (Michell 1987). This treatment of light ensured that by the time the pilgrim reaches the innermost chamber (garbhagriha) his eyes slowly becomes accustomed to the darkness and that he is in the state of mind befitting worship and is no longer plagued by worldly thoughts. Therefore, the hall or the halls before the inner sanctum are kept in semi-darkness, whereas the innermost sanctum is pitch dark. During this journey one passes through many doorways, colonnaded halls and corridors to the sacred spaces beyond. The sacred carvings on the walls, pillars, architrave and ceilings of the interior compartments, have a profound impact on the mind of the devotee. Attuned and prepared the devotee approaches the sanctum and stops at the door, which is the last member to show the carvings. The presence of the river goddesses on the doorframe purifies the devotee of all earthly taints; his mind and soul are now concentrated on the enshrined divinity whose tutelary symbol is carved on the lintel. The worship is offered to the deity in the sanctum sanctorum individually by each devotee, for the Hindu shrine is primarily a place for individual self-realization and is not intended for mass prayer or congregational worship (Deva 1995). According to Michell (1987), the progression into the temple is thus a ritual movement where the devotee goes through the dynamic experience of the temple architecture before reaching the dark innermost sacred chamber.

Principles of Daylighting Design

Daylight is the most recently rediscovered realm of architecture (Moore 1985). Once inseparable from the practice of fine building design, lighting by natural means began to be regarded as anachronistic early in the twentieth century when electric lighting became both practical and economical. Instant, safe, predictable, and absolute,

artificial lighting had tended to overwhelm building design since the industrial revolution. Electricity has also made possible constant illumination levels that do not reflect the natural rhythms and the unpredictable variations of each day's new light (Moore 1985). But now the dynamic nature of daylight is seen as a virtue rather than a liability. It satisfies the biological need for relating to the natural rhythms of the day. It also creates drama that is much more stimulating than a completely consistent electric lighting scheme. The basic goal of day lighting is to supply sufficient quality of light while minimizing direct glare, veiling reflections and excessive brightness ratios. The orientation and form of a building are critical to a successful day-lighting scheme (Lechner 1991, 2000).

Daylight that enters an opening can have several sources: direct sunlight, clear sky, clouds, or reflections from the ground and nearby buildings. The light from each source varies in quantity as well as in quality such as color, diffuse-ness and efficacy (the power to produce an effect). A daylight design, which can work under the conditions of an overcast sky or a clear sky, can work under most other sky conditions. The illumination from an overcast day is quite low but it is sufficient to perform visual tasks indoors if sufficient quantity of light can be drawn in. On the other hand the daylight from clear skies consists of the two components of skylight and direct sunlight. The light from the blue sky is diffused and of low brightness, while the direct sunlight is extremely bright (Lechner 1991, 2000).

Lechner (1991, 2000) summarized numerous studies on natural lighting design (Hopkinson 1966; Egan 1983; Brown 1985; Moore 1985; Schiller 1985; Lam 1977, 1986; Robins 1986). His summary drew several lighting design guidelines and recommendations, which emphasize the relationship between light and darkness as well as light and objects, and focus on the designated light quality. These guidelines have been elaborated in the Method section (see Research Instruments). These principles of day-lighting design serve also as the basis for the computerized lighting simulation that illustrates the quality and quantity of light in buildings.

In summary, this background review introduces the link between religion and light and shows the importance of natural light in creating the holy atmosphere in sacred places in general and in Hindu temples in particular. In addition, it outlines the principles of lighting design to be used later as the basis of one of the method for analysis.

CONCEPTUAL MODEL AND HYPOTHESES

A review of the existing literature shows that there has been a very definite relationship between religion and light throughout time in various cultures around the world. This link is expressed in a conceptual model shown in Figure 1. The model illustrates that each religion requires a certain quality of light in its sacred buildings, which effects the final architectural or building solution, adopted in order to achieve the actual quality of light. On the other hand, time brings about changes in the size of the building components triggering developments in building technologies, which also includes changes in the technology of lighting design. This in turn also affects the final solution of actual quality of achieved light.

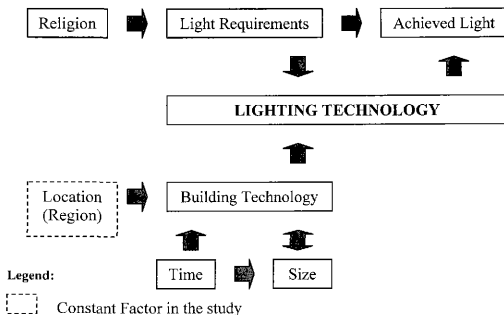


Figure 1: The study's conceptual model

Light design technology (lighting technology) in the model refers to the various techniques and methods used to incorporate natural light in sacred monuments. These include the use of natural lighting systems like skylights, clerestories and window openings, as well as the effect of various materials, colors and building components on the quality of light.

The conceptual model focuses first on how religion dictates light requirements in a sacred space, which in turn (should/could) affect the actual achieved light (see Figure 1). The treatment of these requirements is via the existing technology of that time. Hence, the first hypothesis (H_1) of the study examines the linkage between religion and the accomplished quality of light in the building and shows that *the principles of religion govern the treatment and quality of light in sacred monuments*.

The second part of the conceptual model highlights the evolution of lighting design technology that mediates between the religious light requirements and the actual achieved light. Advancement of building technology in general (e.g. materials, openings, colors) and changes in building size, affect components of lighting technology. Although there is an influence of geographical location (region) on building technology, the paper examines only one region (state of Tamilnadu) and therefore this factor remains constant and controlled. Both building technology and building size, which affects lighting technology, are a function of time. Therefore, the study's second hypothesis (H_2) suggests that *accomplishment of light design technology (H_1), is a function of time as expressed through building technology and building size*.

The paper examines these hypotheses with constant factors of faith (Hindu) to control religious requirements, and of location (the southern region of Tamilnadu, India) to control light quality. For H_1 , the independent variable is the religious light requirements; the dependent variable is the actual achieved light. For H_2 the independent variable is time as expressed through advanced building technology and changes of size; the dependent variable is the treatment of light.

METHOD

The research examines the treatment of natural light across time in three Hindu temples that were built in the state of Tamilnadu in India. The temples are, the Shore temples at Mahabalipuram (700 AD); the Brihadesvara temple at Tanjore (1010 AD); the Meenakshi-Sundareshwara temple at Madurai (1660 AD). The sample monuments are built within the same geographic region of the state of Tamilnadu, which is situated on the southeast coast of India (see Figures 2 & 3). This region becomes overcast with clouds during the monsoon season (from June to November), but receives strong sunlight during the rest of the year. The study uses the climatic data (the quality of light and cloud cover) for each of the sites, from data compiled by local weather stations. When a specific site of the temples does not include a weather station, the data used in this project is taken from the tables of the surrogate cities located near the temples.⁵



Figure 2: Map of India showing the region of study

⁵ These cities are Madras for Mahabalipuram and Tanjore for Madurai.



Figure 3: Map of South India showing the region of Tamilnadu

The rationale behind the selection of the region of Tamilnadu is mainly because this is the only region in India which never fully came under an Islamic power. The Muslim invasion in India started in the 1100 AD and continued irresistibly over a period of five centuries, moving towards the south of Deccan region. Only the tip of the southern region of Tamilnadu escaped Islamic domination (Stierlin 1998). As a result, this region did not suffer the mass destruction of temples, which was normally inflicted by the Muslim rulers on the regions conquered by them. Nor were any of the monuments ever influenced by Islamic architecture. Hence, this was the only region in India which was totally under the influence of Hindu religion and architecture even under the British rule from 1600 AD (Tadgell 1990). The various dynasties in that region were constantly engaged in building bigger and better temples. The three monuments were chosen mainly because they represent the three most important dynasties of that region, between 600AD and 1700AD.

In pursuing the objectives as stated in the Introduction and testing the two hypotheses as described in the conceptual model, the study utilized a multi method analyses that includes the following:

- A qualitative comparative analysis that comprises of morphological analysis according to accepted design guidelines and techniques for incorporating natural light in buildings.
- A quantitative analysis in the form of a computerized light simulation using Lightscape.

Study Sample

General

This research focuses on the region of Tamilnadu, where the sacred monuments essentially belong to the Dravida style of architecture. As part of south India, its temple-architecture developed along independent lines from those of north India, and gave rise to building-modes quite distinctive in concept and aesthetics⁶. Since the southern form of temple architecture was being practiced only in the state of Tamilnadu, anciently known as Dravidadesha, it is referred to as the Dravidian style (Brown 1968). The southern style can be grouped into the following five broad chronological divisions corresponding to the five principal dynasties which successively ruled over the region and patronized and largely molded the growth of architecture in south India: Pallava (600 AD-900 AD); Chola (900 AD-1150 AD); Pandya (1150 AD-1350 AD); Vijayanagara (1350 AD-1565 AD); Nayaka (1600 AD-1750 AD) (Deva 1995).

The Pallavas, (600 AD-900 AD) provided the foundations of the Dravidian style and had the most effect on the architecture of this region (Brown 1968). In later years, the old forms were followed religiously with the only exception being the increased monumentality and size of the sacred structures (Harle 1986).

⁶ The Indo-Aryan style is confined to north India while the Dravidian style is found in the southern part of India.

In the 7th century AD a series of five freestanding monoliths were built in Mamallapuram by the Pallava dynasty. These monuments, called the rathas (celestial chariots), provide vital information regarding the genesis of south Indian architectural forms (Huntington 1993). These rathas are models, hewn out of a granite ridge and are considered the forerunners of the south Indian stone temple. Most of them have no interior, since the builders were primarily concerned with trying to achieve the most suitable external form (Volwahren 1969). The entire Dravida style is based on the symbolic scheme of the rock-cut models of the rathas and is a transposition of the formula of these monolithic temples (Stierlin 1998).

Each of the five rathas is a replica of a separate type of religious structure, which were common at the time. With the exception of one, they are all derived from the two types of Buddhist structures, the vihara (monastery) and the chaitya hall (temple). The only exception is the one known as the Draupadi ratha, the smallest and the simplest structure in the series. This monument is just a cell with a roof designed in the shape of a thatched structure, which indicates that it was a form of shrine belonging to a village community. The other four rathas, though varying in size and details, are similar in architectural style and resemble a Buddhist vihara (monastery), where the monk cells are arranged around an inner court. The inner court of the Buddhist monasteries was later covered with a flat roof on pillars. In the course of time, as the community of monks occupying the monastery increased other stories were added, and, finally, the entire structure was crowned with a dome. In the rock cut interpretation of this composition in the rathas, the Buddhist monk cells have lost their original character and intention, and have become modified into ornamental turrets along with other alterations suitable for its new purpose. The transformation from a Buddhist hostel to a Hindu shrine is most clearly illustrated in the largest ratha, called the Dharmaraja ratha (Brown 1968).

The Dharmaraja ratha has a square ground plan with open pillared verandahs, forming the base of the terraced pyramidal shikhar (tower) above, which represents the upper stories of the Buddhist vihara (see Figure 4). The entire structure is crowned by a

bulbous dome, which is repeated in smaller size on each of the lower levels of the terraced super-structure. This ratha was chosen from a variety of possible types of temple forms, by successive dynasties, as the model for the Dravida style of temple architecture (Volwahren 1969).

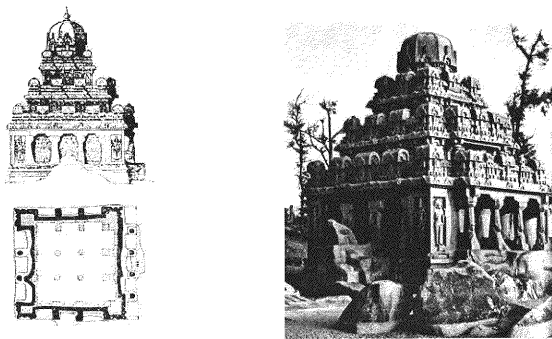
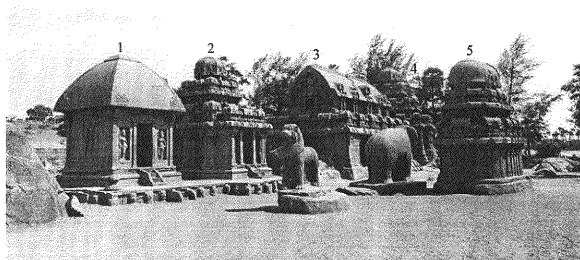


Figure 4: Dharmaraja ratha, Mahabalipuram: Plan, elevation and view (Source: Volwahren 1969)

The Arjuna ratha is similar to the Dharmaraja ratha in its form. The Bhima ratha is based on the Buddhist chaitya hall (temple). It is oblong in plan and rises up to two or more diminishing stories and is covered with a barrel roof with a gable end similar to the chaitya halls (see Figure 5). Along with being a prototype for some of the later south Indian temples, this ratha also represents the pattern which gave rise to one of the chief characters of the Dravidian style, the south Indian gopurams (entrance gateways). The

Nakula-Sahadeva ratha though much smaller in size, is also similar to the Dharmaraja ratha in its form, but has an oblong roof (Brown 1968).

The exterior lower storey walls of all the rathas are carved into a series of niches containing figures, each separated by pilasters with bracketed capitals. This format, of figures contained within niches separated by pilasters is typical of south Indian temple architecture. Similar to the rathas, the superstructure of the Dravidian style was in the form of stories that diminished in size as they ascended forming a pyramidal profile (see Figure 5). These model forms were the basis of the south Indian sacred monuments seen in the later Chola and Nayaka periods (Huntington 1993).



Legend

- | | | |
|-------------------|---------------------|--------------------------|
| 1. Draupadi ratha | 3. Bhima ratha | 5. Nakula-Sahadeva ratha |
| 2. Arjuna ratha | 4. Dharmaraja ratha | |

Figure 5: Rathas, Mahabalipuram: View from the north (Source: Volwahren 1969)

Case Studies

Shore Temple, Mahabalipuram

The Shore Temple (as it is named today) was built by the southern Pallava dynasty of kings on the extreme foreshore of the ancient port of Mamallapuram, also known as Mahabalipuram. The Pallavas ruled the southeastern coast now known as the state of Tamilnadu and were one of the major powers in this southern region. The Shore temple was built during the reign of Nrsimhavarman II Rajasimha, (690 AD-728 AD) one of the most illustrious Pallava kings. It was the first structure of the Pallava dynasty to be constructed of dressed stone and it dates back to 700 AD (Brown 1968).

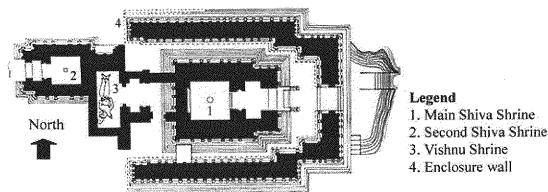
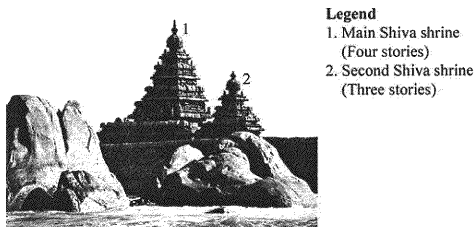


Figure 6: Shore Temple, Mahabalipuram: Plan (Source: Huntington 1993)

Figure 6 illustrates the three shrines of the temple complex. The main four-storied Shiva (a Hindu god) temple faces the sea on the east whereas a second three-storied smaller temple of Shiva faces the opposite direction. Each temple is square in plan and enshrines an emblem of the deity (Deva 1995). Above the two Shiva shrines, rise the steeply pyramidal superstructures known as vimanas (towers), which are capped by octagonal domes (Michell 1989) (see Figure 7). Wedged in between these two sanctuaries, is the third shrine, which is a rectangular hall without a superstructure. The

interior of this shrine consists of an image of sleeping Vishnu (a Hindu god), cut from a natural outcrop of a granite boulder, and is the oldest structure within the temple complex (Finegan 1989) (see Figure 6). The location of the main temple on the ocean's edge left no room for a mandapa (forecourt or an assembly hall) or an arddhamandapa (vestibule). As a result the entrance into the shrine is from the west through a richly ornamented doorway. The surrounding wall of the enclosure was an imposing structure, its parapet and coping crowned by figures of kneeling bulls, while at close interval all around the exterior projected boldly carved lion pilasters. In addition a series of carved narrative panels lined the inside of the enclosure wall (Brown 1968).



Legend

1. Main Shiva shrine
(Four stories)
2. Second Shiva shrine
(Three stories)

Figure 7: Shore Temple, Mahabalipuram: View from the sea (Source: Volwahren 1969)

The underlying idea of the temple was that the eastward-facing shrine should be illuminated by the first rays of the rising sun, as well as be plainly visible to those approaching the harbor. It was a landmark by the day and a beacon by night. At night, a light was lit on a tall stone pillar to the east of the temple in order to guide the approaching ships (Brown 1968). The temple was extremely unusual due to this combination of holy light serving as a lighthouse on the sea front. In addition, an

opening was created in the eastern outer wall of the temple at a point, which could not be reached from the shore, in order to provide the mariners with a direct glimpse of the garbhagriha (innermost sanctuary) (Volwahren 1969).

Portions of the surrounding outer rectangular enclosure of the temple, consisted of a system of shallow cisterns, which could be flooded on occasions to create a kind of water temple. The water to feed this system was brought by a canal and conveyed by sluices throughout the building, any overflow was carried down a rocky cascade on the eastern side of the shrine and into the sea (Brown 1968).

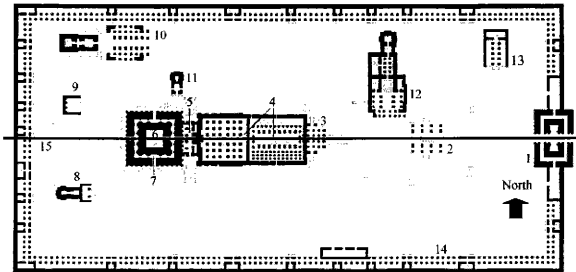
Some of the bedrock was incorporated into the plinth and the lowest base moldings in certain portions of the shrine. The entire construction of the temple otherwise, is a dry stone masonry, consisting of carefully dressed blocks of black granite (Stierlin 1998). Today most of the sculptures that were carved in the stone are weathered beyond recognition by exposure to salt water. But in spite of the ceaseless activity of the sea on one side and the menace of the drifting sands on the other, the twin vimanas (towers) are still erect and the shrines remain intact after twelve centuries (see Figure 7). It serves as a living record of the excellent masonry workmanship as well as the quality of the materials used (Brown 1968).

Due to the retreat of the shoreline, today the temple stands on the edge of the water washed by the sea waves. Part of the “salvage” work undertaken by UNESCO was to construct a massive retaining wall to keep the sea waves from beating against the walls of the monument (Stierlin 1998). In addition, the area around the monument has been paved with concrete to keep the drifting sands at bay.

In spite of the erosion and the changes in its original character the architectural proportions of the temple and the graceful soaring quality of the vimana, combined with their natural setting on the seashore render this structure as one of the finest monuments and an architectural masterpiece (Deva 1995).

Brihadeshvara Temple, Tanjore

The Brihadeshvara temple was built around 1010 AD within the temple town of Tanjore, by the monarch of the powerful Chola dynasty, Rajaraja, the great (985 AD-1014 AD). The city of Tanjore was the capital of the Chola dynasty, which held sway over the whole of southern India between 836 AD and 1267 AD. The Brihadeshvara (or Rajarajeshvara) temple, dedicated to Shiva, was built during a span of six years, and reflects the prosperity and opulence of the Chola kingdom. It is not only a monument to the Chola power but is also one of the finest architectural examples of intricate craftsmanship in stone (Michell 1989).

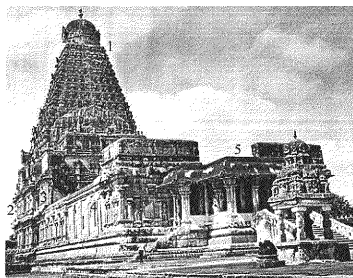


Legend

- | | |
|---|-----------------------------------|
| 1. Gopuras (gateways) | 9. Karuvur Devar shrine |
| 2. Nandi pavilion | 10. Subrahmanya shrine |
| 3. Entrance porch | 11. Chandeshvara shrine |
| 4. Two adjoining mandapas | 12. Amman shrine |
| 5. Antarala (vestibule) | 13. Natraja mandapa |
| 6. Garbhagriha (innermost cell) | 14. Enclosure wall with colonnade |
| 7. Pradakshinapath (ambulatory passage) | 15. East-West axis |
| 8. Ganpati shrine | |

Figure 8: Brihadeshvara Temple, Tanjore: Plan (Source: Stierlin 1998)

Figure 8 shows the linear plan of the Brihadeshwara temple that stands in the middle of a large rectangular walled courtyard. This enclosed space can be entered on the east through two gateways. The 150m x 75m enclosure wall around the courtyard is lined with a colonnade on all the sides and includes small subsidiary shrines. The entrance is dominated by gopuras (pyramidal gateways), with vaulted salas (roofs) and adorned with various sculptures and guardian figures. The gopuras lead towards a pavilion on an east-west axis housing a six meters long monolithic representation of Nandi (Shiva's vehicle, the bull). The pavilion has slender columns with intricate carvings (Michell 1989). The entire structure of the temple is centrally aligned with the Nandi pavilion and the gopuras (Brown 1968).



Legend

1. Vimana (inner-most shrine from base to finial)
2. Garbhagriha (innermost cell)
3. Antarala (vestibule)
4. Mandapa
5. Entrance porch

Figure 9: Brihadeshwara Temple, Tanjore: View from the east (Source: Harle 1986)

Further west is the entrance porch of the Brihadeshwara temple, which leads into two adjoining mandapas (Michell 1989). The mandapas are not contemporaneous with the construction of the sanctuary. Art historians believe that they were either built subsequent to the collapse of an original structure, or they had remained incomplete and

were finished several centuries later (Pichard 1995). The mandapa adjoins the antarala (vestibule) and the garbhagriha (innermost cell) on the west (see Figure 9). The walls of the antarala are triple storeyed with doorways on the north and south sides, which can be accessed by a monumental set of stairs. The square garbhagriha is raised on a high plinth and surrounded by a narrow pradakshinapath (surrounding ambulatory passageway) with four cardinal openings (Michell 1989). However, the absence of a stairway makes these openings inaccessible from the courtyard. As a result these openings are considered as token doors, the real function of which is that of windows (Pichard 1995). Each side of the square garbhagriha measures around 8 meters and in the middle sits a colossal 3.66 meters (12 ft) high linga⁷, which is elevated on a circular pedestal (Michell 1989). Due to increase in the size of Shiva's emblem in this temple, the priests could no longer perform the ritual in which the linga is anointed with milk and decorated with flowers. As a result an upper gallery was created in the garbhagriha making the garbhagriha a double storeyed structure (Stierlin 1998). The walls and the ceiling of the pradakshinapath are extensively adorned with mural paintings (Michell 1989).

Figure 10 demonstrates the steeply pyramidal stone tower, which is a gigantic reproduction of the Dravidian vimana (pyramidal spire), rises to a height of approximately 66 metres (217 ft) above the garbhagriha. Thirteen diminishing stories, each with pilastered walls, an eave and parapet, ascend towards an octagonal dome-like roof with a gold plated copper kalash (stupi) at the apex (Michell 1989, Deva 1995). During recent repair works on the vimana, it was discovered that the octagonal cap stone at the top of the terraced pyramid is not built of single stone weighing 80 tons but is made up of two granite stones weighing 40 tons each. Granite stone was used throughout in the construction of the Brihadeshvara temple and the subsidiary shrines except in the superstructures of the gopuras (entrance gateways), which are made of

⁷ Shiva as the phallic emblem, usually mounted on a yoni (the female vulva) pedestal as the principal object of worship (Michell 1989).

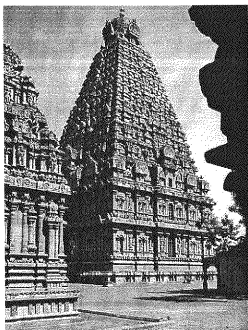


Figure 10: Brihadeshvara Temple, Tanjore: The Vimana (Source: Stierlin 1998)

brick and plaster (Michell 1989). Till the time when the temple at Tanjore was commissioned, none of the religious architectural structures had attempted to go higher than 18 meters (60 ft). The ambitious superstructure of the Brihadeshvara temple at Tanjore required that each level of the vimana be proportionately enlarged in plan, which contributed to the enormous cube of the garbhagriha at the base of the vimana. In order to accentuate the soaring verticality of the converging lines of the pyramid, the horizontal tiers of each of its thirteen storeys were suppressed (Grover 1980). The temple structure is embellished with colossal images of door-guardians at the door entrances as well as numerous images of deities at significant positions, some of which are life size. The images in the niches of the vimana portray various forms of Shiva, to whom the temple is dedicated (Michell 1989).

Subsidiary structures within the court enclosure include a Natraja mandapa in the northeast corner of the enclosure, the Chandeshvara shrine to the north of the main shrine, the Subrahmanya shrine in the northwest corner of the court and the Ganpati

shrine in the southwest corner of the court. It also includes the Karuvur Devar shrine to the west of the courtyard and the Amman shrine to the north of the Nandi pavilion (see Figure 8) (Michell 1989, Pichard 1995). Today the temple is on the *World Heritage Monuments* list (Seshadri 1998).

Meenakshi-Sundareshwara Temple, Madurai

From 16th century onwards until the coming of the British, the extreme southern tip of the Indian peninsula was ruled by local governors known as Nayaks, who had asserted their independence from the powerful Hindu Vijayanagara empire in south India. Of the many powerful Nayaka rulers, Tirumala Nayak (1623 AD-1660 AD) is considered as one of the most powerful governor. The temple of Madurai was built under his patronage to celebrate the marriage of the Meenakshi and Sundareshwara incarnations of Parvati and Shiva respectively. As a result there are two garbhagrihas within the temple complex, one dedicated to Shiva (also Sundareshwara) and the other to Parvati (also Meenakshi) Shiva's consort, making it a twin shrine within a single temple complex. The ceremonial marriage of Meenakshi, the goddess of fertility to Sundareshwara is the most important festival in the city of Madurai every year (Michell 1989).

Due to the enlargement of the Hindu ritual of worship leading to additional structures and ancillary buildings, the temples during this period began to resemble cities in themselves and had to be planned like a town (see Figure 11). The great temple-city of Madurai was thus designed as a series of concentric courtyards or prakarmas. The prakarmas were endowed with diminishing religious value directly proportional to their distance from the deity in the inner shrine. The outermost circle accommodated structures of practical rather than spiritual nature, like the account offices, dormitories for pilgrims, kitchens and shops dealing in essential items for the rituals, maintenance workshops and parking areas for the growing number of wooden festive chariots. The lower class people who were needed to service these areas were permitted only into the outlying areas. The inner prakarmas contained pavilions for

devotional singing and story telling, for ritual ablution and guest houses for important visitors. In the innermost courts were the kitchens of the Brahmin priests, the pavilions for the dancing girls and the treasury. Admittance to these areas was restricted to the upper caste Hindus only. The actual sanctum containing the image of the God was open only to the officiating priest and none else, including royalty (Grover 1980).

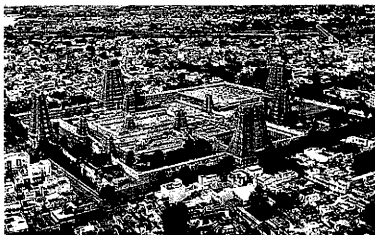


Figure 11: Meenakshi-Sundareshwara Temple, Madurai: Arial view (Source: Michell 1995)

Figure 12 illustrates the entire complex of the Meenakshi-Sundareshwara temple contained within a rectangle of high walls with four towering gopuras (gateways), in the middle of each side. Within the six hectares enclosure is a complex of colonnades, galleries, pillared mandapas (halls), courtyards, tank, stores, ancillary shrines and at the core, built on two parallel east-west axis, are the two temples of Shiva as Sundareshwara and Parvati as Meenakshi (Michell 1989).

Inside the outer wall another inner rectangular wall encloses the Sundareshwara shrine with smaller gopuras in the middle on each side. The entrance is through the huge gopura of the outer wall on the east. The eastern gopura open into a two hundred

feet long pillared avenue called the Viravasantaraya mandapa, in which the idol of Nandi (Shiva's vehicle, the bull) is placed.

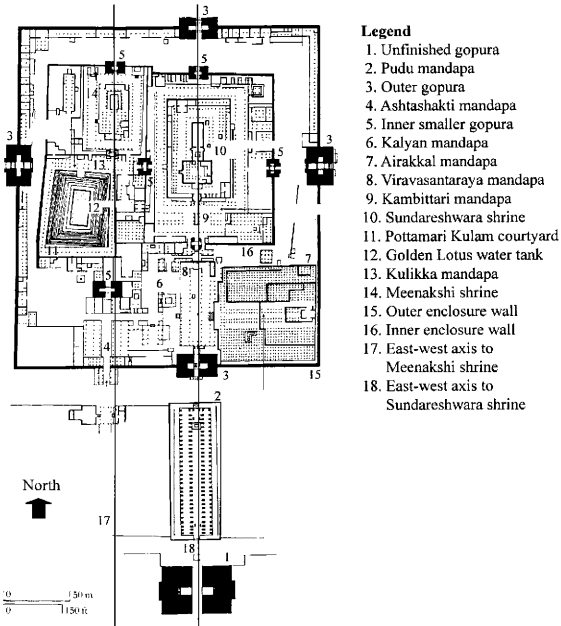


Figure 12: Meenakshi-Sundareshwara Temple, Madurai: Plan (Source: Michell 1989)

To the south of the Viravasantaraya mandapa is the Kalyan mandapa, where the images of Meenakshi and Sundareshwara are brought during the festival celebrating their marriage. The Viravasantaraya mandapa leads to the smaller gopura in the inner walled enclosure through which one enters the Kambittari mandapa (Michell 1989). Most of the space inside the inner wall is covered with a flat roof but is partly open on the northern side. Within it is another covered court with only one entrance doorway on the east. This last enclosure consists of three parts, an assembly hall, the vestibule, and the most sacred innermost sanctum, the garbhagriha where the image of Sundareshwara is placed. The garbhagriha is surmounted by a small vimana, which penetrates through the flat roof covering the inner part of the temple (Brown 1968).

The other shrine of the temple dedicated to Sundareshwara's consort, goddess Meenakshi, is an enclosure attached to the south side of the adjacent Sundareshwara sanctuary. This temple can be entered through the Ashtashakti mandapa (porch of the eight goddesses) lying to the south of the large eastern gopura on the outer wall. This porch leads into a pillared mandapa used for shops and stores (Michell 1989). At the far end of this mandapa lies another gopura on an axis with the Meenakshi shrine marking an independent entrance to the Meenakshi temple by forming a direct processional passage towards the shrine from the outside. On the southwest of this gopura is the courtyard of Pottamari Kulam, in which lies the rectangular Golden Lotus water tank at an angle. Steps and a pillared portico surround the tank on its four sides and a brass lamp-column stands in the middle of the tank (Brown 1968). The colonnade around the tank is decorated with murals in distinctive brown and ochre colors. The ceilings are painted with large medallions. On the western side of the tank lies the Kulikka mandapa with finely carved figures on the columns. On the western side of the tank lies an entrance doorway, which leads to the inner courtyard of the Meenakshi shrine. This inner covered court has a small gopura on its west wall and consists of a mandapa and the sacred garbhagriha. Rising above the flat roof of the covered court is the vimana crowing the garbhagriha. Just outside this inner courtyard on the north is a gopura, which connects both the temple complexes.

Another important structure in the temple plan is the 5000 m² hall of the thousand pillars called the Airakkal mandapa, which was added at a later date to the temple complex. This hall occupies the northeast part of the temple complex just inside the outer wall. The symmetrical interior consists of central aisle with a double row of columns on either side, leading to a small subsidiary shrine at its northern end (Brown 1968). There are 985 elaborately decorated columns in this mandapa. The piers have numerous divinities, female musicians and attendant figures carved in full relief on to the shafts. In addition, throughout the entire complex, the piers, brackets and the supporting elements in all the courts and halls are profusely carved with animal and human figures. (Michell 1989).

Outside the complex, in front of the east gopura, is the Pudu mandapa. This is a long hall with magnificently carved piers. The western end of the hall has a small pavilion fashioned out of polished black granite. Beyond this mandapa on the east stands the lowest story of an unfinished gopura (Michell 1989).

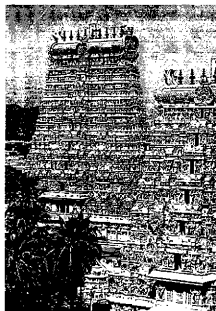


Figure 13: Meenakshi-Sundareshwara Temple, Madurai: Gopura (Source: Stierlin 1998)

Figure 13 shows the gopuras at Madurai, which are elaborately adorned and are exceptional for their elongated proportions and curved profiles. The largest gopura is on the southern outer wall and reaches a height of 48 metres (Michell 1989). Rising from high granite base, the brick and painted stucco superstructures of the gopuras taper with a slight curve and end in the barrel-vaulted sala (roof). Each level of the superstructure diminishes in size as they ascend and consist of openings and porticos to admit light into the hollow chambers (Huntington 1993). The entire structure of the gopura is covered with figures of divinities, celestial beings, monsters, guardians and animals in the same order, with animals occupying the lower stories of the gopura and the divine figures on the uppermost stories. All these elements are encrusted with plaster decoration and painted in vivid colors (Michell 1989). In the mid-twentieth century this complex was renovated and the gopuras (gate-towers) were painted in its original bright colors (Michell 1989).

Due to the size of the temple and the lack of detailed information, only the inner-most sacred part of the Sundareshwara and the Meenakshi shrines will be considered for this study.

Research Instruments

Lighting Design Guidelines

As indicated before (see literature review), Norbert Lechner (1991, 2000) summarized the research conducted on lighting design in a series of guidelines. These guidelines are based on observations and studies of lighting design and are accepted for contemporary treatment of natural light. This study uses Lechner's (1991, 2000) general lighting design guidelines as a tool to analyze the natural lighting system in each of the sample temples. Furthermore, the study utilizes the specific strategies and techniques for admitting daylight into buildings as described by Lechner (1991, 2000) and Aitken (1998). This section describes in brief each of the design guidelines and the techniques or strategies for achieving these goals. The reference for the guidelines is Lechner (1991, 2000). The reference for the strategies and techniques are Lechner (1991, 2000)

and Aitken (1998), where Aitken's strategies are described following those of Lechner's.

1. Lighting Program: To establish a lighting program.

- Determine the visual task in each space.
- Determine the function of each space.

2. Uniform Illumination Level: To illuminate only those things that need to be seen. This includes the ceiling, wall, details and some interior elements. The light reflected from these surfaces, supply much of the required illumination. The reflection helps to get more light deeper into the building and raise the illumination level while reducing the illumination gradient across the space.

- Use north and south directions for facing windows and clerestories.
- Use windows placed high near the ceiling. This allows the daylight reflected from the outside to strike the ceiling without being blocked and to penetrate deeper into the structure. A suggested rule of the thumb is that daylight penetrates into a building in useful amounts to a distance of about two to two and one-half times the height of the window. So by placing the windows high, the daylight that reflects off the exterior surfaces is washed over the ceiling and reflects back into the interior space.
- Use clerestories and skylights to bring daylight deeper into interior spaces. Multiple sources of clerestories and skylights distributed across the space balance side lighting from windows, fill in shadows, and provide uniform and contrast-free light.
- Use glass-topped atriums to act as buffer zones for thermal control along with penetration of daylight deep into the core of a building and provide multi-directional day light.

3. Avoid Direct Glare: To avoid direct glare by manipulating the geometry between the viewer and the light source. This glare is aggravated if the walls adjacent to the windows are not illuminated and therefore quite dark.

- Use louvers or other building elements to baffle the light sources from normal viewing angles in order to prevent glare. The main light source should never be in front of the viewer.
 - Use shading to reduce sunlight to a usable level and to control glare and overheating.
 - Use high reflectance matte finishes for most surfaces especially large area surfaces. This is to reflect and diffuse building surfaces to redirect and enhance daylight penetration.
 - Use appropriate glass to avoid direct glare.
4. Avoid Veiling Reflections: To prevent or minimize veiling reflections especially from skylights and clerestory windows. Although the low angle light from windows is usually not a source of veiling reflections, the light from overhead openings is.
- Use controlled daylight from clerestories and skylights.
 - Use low angle light from openings.
5. Direct and Diffused Light: To have a combination of direct and diffused light. Direct lighting can cause very dark shadows and should therefore be diffused by means of multiple reflections off the ceiling and walls. The resulting soft shadows and shading allow us to understand the three-dimensional quality of the world.
- Use openings to collect daylight, but do not introduce more light than is required.
 - Use the smallest windows possible to collect the required amount of light and minimize the thermal penalties.
 - Use the light reflected from exterior objects like buildings, surfaces etc. This reflected light bounces upward through glass to be further diffused and reflected by the ceiling.
 - Use translucent exterior building materials that simultaneously provide thermal protection and diffused daylight. These materials could be glass, plastic etc
6. Avoid Brightness Ratios: To avoid large brightness ratios that force the eye to readapt constantly. When the beam of sunlight creates a focussed light over part of the work area, severe and unacceptable brightness ratios will exist.

- Use openings to collect daylight, but do not introduce more light than is required.
7. Avoid Direct Sunlight: To utilize the drama and excitement of direct sunlight as a major design element in areas where there are no critical visual tasks. In all spaces the dynamic nature of daylight should be seen as an asset rather than a liability. The constantly changing nature of daylight need not be eliminated.
- Use the drama and effect of darkness.
 - Use controlled sunlight so that interior spaces receive “daylight” and “skylight” but not direct sunlight.
8. Flexibility and Quality: To focus on flexibility and quality is more important than on the quantity of light. After the minimum quantity of light is achieved, the quality of the light becomes more important than the quantity.
- Use direct and indirect daylight in the required combination.

3-D Computer Models and Daylight Simulation Method

Lightscape is an advanced lighting and visualization application used to create accurate images of how a 3D model of a space, or object, would appear if physically built. Lightscape runs on Windows application only. For this study Lightscape was installed on a Silicon Graphics 320 computer with a 486,136 KB RAM. The computer is a Microsoft Windows NT Workstation Version 4.0 updated with Service Pack 4 and has Intel Pentium III microprocessors. In this section the description of the software has been taken from Autodesk Manual (1999) for Lightscape users and learners.

Since Lightscape is founded on a physically based simulation of the propagation of light through the environment, the results are not only highly realistic renderings, but also accurate measurements of the distribution of light within the scene. Lightscape uses both radiosity and ray tracing technology (elaborated later) as well as physical based interface for defining lights and materials and thus has many unique advantages over other rendering technologies (Autodesk 1999). Lightscape daylight simulation was used in this study for its quantitative analysis. According to Autodesk (1999) the characteristics of Lightscape are:

- **Realism:**
Lightscape accurately calculates how light propagates within an environment. One can obtain subtle but significant lighting effects and produce images of natural realism not attainable with other rendering techniques.
- **Physically based lighting:**
Lightscape works with actual photometric (light energy) values and therefore lights can be set up intuitively as they would be in the real world. One can also specify natural daylight simply by indicating the location, date, and time of day.
- **Interactivity:**
The result of a radiosity solution is not just a single image but a full 3D representation of the light distribution in an environment. Since the lighting is pre-calculated, Lightscape can display specific views of a fully rendered model much faster than with traditional computer graphics techniques.
- **Progressive refinement**
Unlike other techniques, a Lightscape solution provides instant visual feedback, which continues to improve in quality over time. At any stage in the process, one can alter a surface material or lighting parameter and the system will compensate and display the results without starting the process over.

A 3D model contains geometric data defined in relationships to a 3D Cartesian co-ordinate system, and other information about the material of each object and the lighting. The color of any specific point on a surface in a model is a function of the physical material properties of that surface and the light that illuminates it. Two general shading algorithms, local illumination and global illumination, have been used by Autodesk (1999) to describe how surfaces reflect and transmit light:

- **Local illumination:**
Local illumination algorithms describe how individual surfaces reflect or transmit light. Given a description of light arriving at a surface, these mathematical algorithms predict the intensity, spectral character (color), and distribution of the light leaving that surface.

- Global illumination:

To get more accurate images, it is important to take into account not only the light source, but also how all the surfaces and objects in the environment interact with the light. Some surfaces block light and cast shadows on other surfaces; some surfaces are shiny, reflecting other surfaces; some are transparent, one can see other surfaces through them; and some reflect light onto others. Global illumination algorithms are rendering algorithms that take into account the ways in which light is transferred between the surfaces in the model. Lightscape uses two global illumination algorithms, Ray tracing and Radiosity:

- Ray tracing:

Ray tracing is a very versatile algorithm because of the large range of lighting effects it can model. Its advantages are accurate rendering of direct illumination, shadow, specular reflections (e.g.mirrors), transparency effects, and being memory efficient. Its disadvantages are that it is computationally expensive, time consuming depending on the number of light sources, the process must be repeated for each view, and does not account for diffuse inter-reflections (i.e. images may appear flat).

- Radiosity:

To address the shortcomings of ray tracing algorithm mentioned earlier, an alternative technique called Radiosity was developed for calculating global illumination. Radiosity differs fundamentally from ray tracing. Rather than determining the color for each pixel on a screen, radiosity calculates the intensity for discrete points in the environment. This is accomplished by first dividing the original surfaces into a mesh of smaller surfaces known as elements. The radiosity process calculates the amount of light distributed from each mesh element to every other mesh element. Then it stores the final radiosity values for each element of the mesh.

Its advantages are that it calculates diffuse inter-reflections between surfaces, is view independent for fast display of arbitrary views and produces immediate visual result, progressively improving in accuracy and quality. Its disadvantages are that the 3D mesh requires more memory than the original surfaces, surface-sampling algorithm is more susceptible to imaging artifacts than ray tracing, and it does not account for specular reflections or transparency effects.

Neither radiosity nor ray tracing offers a complete solution for simulating all global illumination effects. Radiosity excels at rendering diffuse-to-diffuse inter-reflections whereas ray tracing excels at rendering specular reflections. By integrating both the techniques, Lightscape offers a full range of visualization possibilities, from fast, interactive lighting studies to combination radiosity/ray traced images of exceptional quality and realism.

Procedure

Data Collection

Data collection on the region, its architecture and about the specific temples was gathered through an extensive literature review of published books and articles through the library collection and the 'Inter Library Loan Service' at the Texas A&M University.

Qualitative Analysis

The first hypothesis (H_1) of the study examines the linkage between religion and the accomplished quality of light in the building and shows that, the principles of religion govern the treatment and quality of light in sacred monuments. The second hypothesis (H_2) suggests that, accomplishment of light design technology (H_1), is a function of time as expressed through building technology and building size. The analysis of H_1 and H_2 was conducted using acceptable lighting design guidelines and

techniques as described in the Research Instruments section. The light quality considered was strong light from clear skies.

The plan and elevations (where available) of each of the three Hindu temples, as published by Stierlin (1998) and Pichard (1995), have been evaluated against the following criteria:

- Lighting Program -Seeing task in each space
 -Spatial function
- Illumination Level -Orientation of openings (north and south)
 -Reflectance from surfaces
 -Presence of clerestories/skylights
 -Uniform distribution of light
- Avoid Direct Glare -Baffling view of daylight sources
 -Sun-protection (Shading, porches, wall thickness)
 -Use high reflectance matte surfaces
- Avoid Veiling Reflection -Controlled daylight from clerestories/skylights
 -Low angle daylight from openings
- Direct & Diffused Light -Controlled daylight from openings
 -Use high reflectance matte surfaces
- Avoid Brightness Ratio -Controlled daylight from clerestories/skylights/openings
- Avoid Direct Sunlight -Use indirect daylight reflected from other surfaces
 -Avoid the use of direct sunlight
- Quality of Light -Use of direct and indirect daylight

The results of the morphological analysis are presented in the form of a comparative table (see Results section, Table 4).

Quantitative Analysis

As mentioned in the qualitative analysis procedure section, the first hypothesis (H_1) of the study examines the linkage between religion and the accomplished quality of

light in the building and shows, that the principles of religion govern the treatment and quality of light in sacred monuments.

The quantitative analysis applies only to the Brihadeshvara temple due to the lack of accurate information on the other two temples. A 3D model of the Brihadeshvara Temple at Tanjore was constructed in AutoCAD based on the documentation drawings by Pierre Pichard (1995), published in the book titled, *The monument and the living presence: Tanjavur, Brhadisvara: An architectural study*. The interior and the exterior of the temple were modeled separately. For the exterior model the entire monument was constructed the way it is visible from the exterior. The drawings were constructed as 3D surfaces⁸ instead of solid walls to optimize it for radiosity processing. The finished model was imported into Lightscape. For the interior model, only the first floor of the temple was constructed since there is no direct or indirect daylight, which enters the first floor through the other floors of the temple. In addition, apart from the first floor, none of the other floors are accessible to the daily worshippers. Also the other floors of the temple are not visible from the interior of the monument. The interior model was also constructed using 3D surfaces and then imported into Lightscape.

Lightscape simulation comprised of two stages – the Preparation stage and the Solution stage (see Figure 14). In the preparation stage, one can edit the geometry, the materials and the lights in the model and save it as a file extension (i.e. .lp). In the solution stage, Lightscape processes the radiosity solution of the model and saves it with a different file extension (i.e. .ls). In this latter stage one can no longer manipulate the geometry or add lights to the model. To modify such changes one has to return to the Lightscape preparation file (.lp file). The parameters for the interior and the exterior models were defined separately and processed individually in Lightscape.

⁸ Surface is any regular planar triangles or convex quadrilaterals.

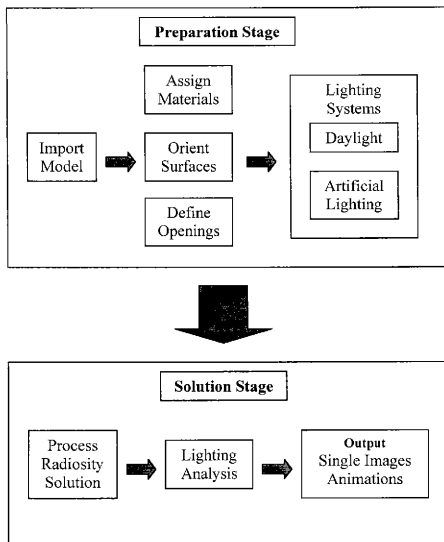


Figure 14: Schematic structure of the lighting simulation process in Lightscape

Preparation Stage

As described in the upper part of Figure 14, after importing the model into Lightscape, the preparation stage includes adjusting the surface orientation, defining and assigning materials to the surfaces as well as defining openings⁹.

Surface orientation determines which side of a surface is considered for calculating its interactions with light. For example, to simulate the lighting in a room, the wall surfaces are oriented toward the inside of the room (Autodesk 1999). As a result, in the case of the interior model of the temple, all the surfaces were oriented towards the interior of the structure. In the case of the exterior model all the surfaces were oriented towards the exterior of the structure.

Since Lightscape is based on physically accurate simulation techniques, it is important to provide accurate material specifications in order to determine how each surface interacts with light. Lightscape provides a library of basic materials that can be used and whose physical parameters such as color, transparency, shininess and refractive index can be modified (Autodesk 1999). The surfaces of the 3D model were assigned the texture and the physical parameters of granite¹⁰ the material from which the entire temple has been built.

To simulate daylight, the direction and intensity of the sun as well as the skylight¹¹ was calculated based on the geographical location, date, time and sky condition settings (Autodesk 1999). Providing the latitude and longitude of the city of Tanjore (10° North Latitude, 79° East Longitude) specified the geographical location of the Brihadeshvara temple on the face of the earth. The north direction was also specified. In addition, since the period of sunrise and sunset are extremely significant in

⁹ See Appendix I-a, to view a sample of the main window in Lightscape.

¹⁰ See Appendix I-b, to view the *Materials properties* window from Lightscape showing the physical parameters specified for granite.

¹¹ Daylight in the environment does not just come from direct sunlight; it also comes from light that is scattered through the atmosphere. The sky is modeled as a dome of infinite radii placed around the scene. The Skylight computes the illumination of a point in the scene with reference to all directions around that point where the sky is visible. The sky brightness is not constant over the sky dome, but keeps changing depending upon the position of the sun (Autodesk 1999).

the Hindu religion, the exterior and the interior model were computed for this period. In addition the models were computed also for high noon (12:00 am) for maximum light. The date of March 21st was specified for the rendering since this day is an equinox when the day and the night are of the same length¹².

The natural lighting of exterior scenes is handled differently than interior scenes. In the interior scenes specific information about where natural light is coming from such as windows and openings are taken into consideration. During the radiosity process the window or opening is treated as a diffuse light source that illuminates the interior of the room. When a surface is marked as an opening, it is not considered as part of the scene and does not receive or reflect light. It is used as a placeholder to indicate that natural lighting can go through it to reach the surfaces of the interior environment. Surfaces marked as openings are not rendered and are not displayed in the model (Autodesk 1999). To compute daylight for the interior of the Brihadeshvara temple, 3D surfaces were created for the doors and windows. Due to the absence of glass or wooden shutters, which could reflect or refract the natural light, these surfaces were defined as openings instead of windows.

To simulate the effect of daylight on an exterior scene, the entire sky dome is used when calculating the illumination contribution from the sky (Autodesk 1999).

Two preparation files were saved at the end of this stage, one of the exterior model (Exterior view.lp) and one for the interior model (Interior View.lp).

Solution Stage

Before initiating the radiosity processing, the processing parameters have to be set. The processing parameters affect the accuracy, speed, and memory usage of a radiosity simulation over the entire scene. The processing parameters were set using the built in Wizard. The Wizard considers specific aspects of a model when setting

¹² See Appendix I-c, to view the *Daylight setup* window from Lightscape, showing the geographical location, date, time and sky condition settings for the model.

parameters, such as the size of the model, if the model is an interior or an exterior scene, the quality of the final rendered image desired¹³.

The model was then initiated. Initiation converts the data describing the surfaces and light sources in the model to a more efficient form for radiosity processing. Once the model was initiated, the radiosity processing was started to compute the direct and indirect lighting in the model.

Six .ls files were created, since the day lighting was calculated using three time periods for the exterior as well as the interior model. Selected views of the model were then rendered using ray tracing, which adds specular reflections and transparency effects to the final images. The output of the solution files were used in three ways:

- Single Images (for Analysis and Presentation)
- Walk-through images (for Presentation)
- Lighting analysis (for Analysis)

The lighting analysis was conducted to visualize the distribution of light over certain select surfaces of the model. The lighting analysis gives statistical data such as averages, minimum and maximum values, and criteria ratings to evaluate luminance (distribution of light reflected off of the surfaces) or illuminance (distribution of light incident on the surfaces) for a specific surface or a point on a surface. Average displays the average value of the target quantity over the selected surface. Maximum and the minimum display the maximum and minimum values of the target quantity over the selected surface. Avg/Min, Max/Min, and Max/Avg display the different ratios of the average, minimum, and maximum values. These three ratios are used in conjunction with the average value to roughly measure the uniformity of the distribution of the light over a selected surface¹⁴ (Autodesk 1999).

¹³ See Appendix I-d, to view the *Process parameters* window from Lightscape, showing the parameter settings for the model.

¹⁴ See Appendix I-e, to view the *Lighting analysis* window from Lightscape, showing a sample analysis.

On selecting a point on a surface of the model, statistical information about the point and the surface was displayed on the statistics window. In addition analytical grids were used in order to display a grid of uniformly spaced sample points and their corresponding luminance or illuminance values for a selected surface¹⁵.

The values obtained from the lighting analysis were then compared to the standard illumination values for lighting design recommended by the Illuminating Engineering Society (IES) (see Table 1). The IES has published a consolidated listing of current illumination recommendations, which is intended to guide the lighting designer in selecting an appropriate illuminance for design and evaluation of lighting systems. Factors such as illuminance, luminance ratios, visual comfort, reflected glare, disability glare, veiling reflections, color and shadows were considered for the illumination considerations (Kaufman 1987).

Table 1: IES values for standard illumination levels for each type of activity in foot candles and lux (Source: Kaufman 1987)

Type of activity	Ft. candles	Lux
General lighting throughout space:		
a. Public spaces with dark surroundings	3	30
b. Simple orientation for short, temporary visits	7.5	75
c. Working spaces where visual tasks are only occasionally performed	15	150
Illumination on task:		
a. Performance of visual task of high contrast or large size	30	300
b. Performance of visual tasks of medium contrast or small size	75	750
c. Performance of visual tasks of low contrast or very small size	150	1500
Illumination on task, obtained by a combination of general and local lighting:		
a. Performance of visual tasks of low contrast and very small size over a prolonged period.	300	3000
b. Performance of very prolonged and exacting visual task	750	7500
c. Performance of very special visual tasks of extremely low contrast and small size	1500	15000

¹⁵ See Appendix I-f, to view the *Lighting analysis* window, showing a sample grid display.

The society established nine ranges of illuminance categories for various types of visual display (tasks) as shown in Table 1. It also recommended ranges of illuminance for specific visual tasks and areas by listing them according to the type of activity (function).

The IES standards for the category of sacred architecture, refers to churches and synagogues only, where lighting design focus on seating arrangement of the congregation and reading of holy writings. In Hindu temples the focus is primarily on the ritual of walking towards the inner most sanctum through the various spaces and on short visits. Table 1 shows the illuminance categories and illuminance values for generic types of interior activities, which can be used when illuminance categories for a specific area/activity cannot be found in the recommended values listing (Kaufman 1987). Therefore, the standard illumination values for the categories of 'Public places with dark surroundings' and 'Simple orientation for short temporary visits' were considered appropriate as a basis for comparison in this study.

RESULTS

The results of this study are based on a multi-method analyses, which includes a qualitative (morphological) analysis and a quantitative (computer simulation) analysis.

Qualitative Analysis

This section describes the analysis of natural light in each of the three Hindu temples using the climatic data published by Takahashi & Arakawa (1981) as well as by Seshadri (1998)¹⁶. Table 2 summarizes the climatic information for Madras (a surrogate city for Mahabalipuram) and Tanjore, which also serves as a surrogate city for Madurai.

Table 2: Comparative display of climatic data for Madras (Shore) and Tanjore (Madurai)

Factor	Madras (Shore)	Tanjore (Madurai)
Latitude	13-00' North	10-47' North
Longitude	80-11' East	79-10' East
Temperature (*Centigrade)	Summer: Maximum 42.8 Minimum 20.1 Winter: Maximum 34.1 Minimum 14.2	Summer: Maximum 36.6 Minimum 32.5 Winter: Maximum 23.5 Minimum 22.8
Average rainfall	121.53 Cms	111.37 Cms
Climate	Hot-humid	Hot-humid
Light quality	Clear strong light (December to May) Cloudy conditions (June to November)	Clear strong light (December to May) Cloudy conditions (June to November)

Each of the three Hindu temples is analyzed according to the design guidelines as described in the Method section using the quality of light as mentioned in Table 2. The morphological analysis shows the influence of religious requirements, time, building size and building technology on the lighting design of these monuments. All

¹⁶ The climatic data is based on data compiled from weather stations (see Method section).

three monuments have been built in the southeast region of the state of Tamilnadu, India. Hence, the monuments share similar geographic and climatic conditions that influence the quality of light, which is clear and strong during December to May and fully or partially overcast during June to November.

Table 3 gives a comparative display of the basic information on the three monuments.

Table 3: Comparative display of basic information on the three temples

	Shore Temple	Brihadeshvara Temple	Meenakshi-Sundareshwara Temple
Time (AD.)	700	1010	1660
Built by	Pallava dynasty	Chola dynasty	Nayak dynasty
Place	Tamilnadu	Tamilnadu	Tamilnadu
Climate	Hot-humid	Hot-humid	Hot-humid
Relative Size	Small	Monumental	City scale
Function of each space	Ritual of worship/ Progressive walking through spaces	Ritual of worship/ Progressive walking through spaces	Ritual of worship/ Progressive walking through spaces
Orientation of temple	East	East	East
Materials	Granite	Granite	Granite
Systems	Daylight	Daylight	Daylight
Largest exposed surface (Reflects Light)	Floor of court paved with granite	Floor of court paved with granite	Floor of court paved with granite

Morphological Analysis of the Treatment of Light in Shore Temple, Mahabalipuram

Lighting Program:

- The spaces in the Shore temple do not have any visual task. The worshippers are required to concentrate their mind only upon God.
- The chief function of each space is the ritual of walking barefoot towards the innermost chamber of the temple.

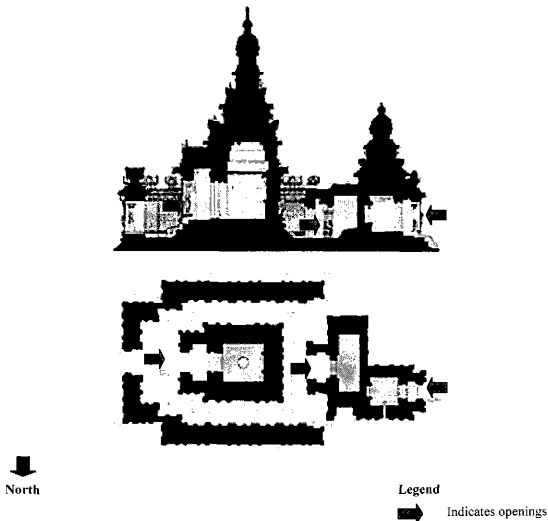


Figure 15: Shore Temple, Mahabalipuram: Plan and section showing openings (Source: Stierlin 1998)

Uniform Illumination Level:

- The monument is oriented on an east-west axis. The entrances are the only openings for the three shrines (see Figure 15). The entrances of the main Shiva shrine and the Vishnu shrine faces east, while that of the smaller Shiva shrine faces west.
- Surface reflectance is minimal due to the use of unpolished granite, a low reflectance surface, as a construction material.

- The monument does not have clerestories or skylights, which could have increased the illumination level (see Figure 15).
- The absence of openings inside the structure and the presence of the huge entrance doorways create an unbalanced distribution of light inside the structure.

Avoid Direct Glare:

- No need for baffling daylight source, due to the absence of openings inside the structure.
- Shading above the doorways does not provide required sun protection.
- Low surface reflectance due to use of granite.

Avoid Veiling Reflections:

- Absence of clerestories and skylights helps to avoid veiling reflections.
- Though the doorways have been provided with a slight shade, it is not enough to provide low angle light.

Direct & Diffused Light:

- Since there are no other openings, entrance doors provide direct light.
- Low reflectance from granite surface provides indirect light.

Avoid Brightness Ratio:

- Though there is an unbalanced distribution of light inside the structure, there isn't enough information to evaluate the brightness ratio inside the structure.

Avoid Direct Sunlight:

- Low reflectance granite surfaces do not provide enough indirect light.
- Entrance doorways provide direct sunlight.

Quality of Light:

- The monument uses direct light from the entrance doors and indirect light from the low reflectance off the granite surfaces.

Morphological Analysis of the Treatment of Light in Brihadeshvara Temple, Tanjore

Lighting Program:

- The spaces in the Brihadeshvara temple do not have any visual task. The worshippers are required to concentrate their mind only upon God.
- The chief function of each space is the ritual of walking barefoot towards the innermost chamber of the temple.

Uniform Illumination Level:

- Though the main entrance door faces east, the other openings (windows and side doors) face north and south (see Figure 16).
- Surface reflectance is minimal due to the use of unpolished granite, a low reflectance surface, as a construction material.
- The monument does not have clerestories or skylights, which could have increased the illumination level.
- Due to the extremely few openings the distribution of light inside the structure is unbalanced.

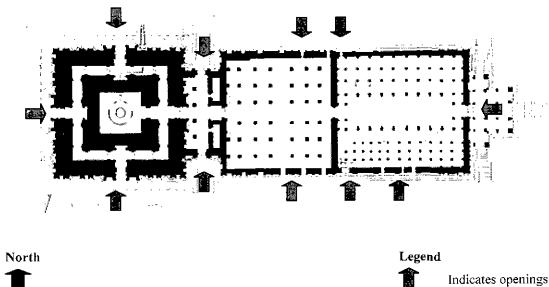


Figure 16: Brihadeshvara Temple, Tanjore: Plan showing openings (Source: Pichard 1995)

Avoid Direct Glare:

- Daylight sources such as windows and side doors have been baffled by the use of colonnade as a building element.
- Covered entrance porch provides sun protection for entrance doorway (see Figure 16). Thickness of the wall (1.2 m) acts as a sun protection for the light entering through the windows. A slight recess in the structure provides sun protection for the side doorways.
- Low surface reflectance due to use of granite.

Avoid Veiling Reflections:

- Absence of clerestories and skylights helps to avoid veiling reflections.
- The presence of the covered porch at the entrance doorway, the low height and small size of windows provides low angle light.

Direct & Diffused Light:

- The covered porch at the entrance along with the small size and the limited number of windows provides controlled direct light inside the structure.
- Low reflectance from granite surface provides indirect light.

Avoid Brightness Ratio:

- As mentioned earlier, controlled and baffled daylight from the openings reduces the brightness ratio.

Avoid Direct Sunlight:

- Direct daylight from the windows and doors are controlled and baffled.
- Low reflectance granite surfaces do not provide enough indirect light.

Quality of Light:

- The monument uses direct light from the various openings and indirect light from the low reflectance off the granite surfaces.

Morphological Analysis of the Treatment of Light in Meenakshi-Sundareshwara Temple, Madurai

Lighting Program:

- As described before a larger part of the outer spaces in the Meenakshi-Sundareshwara temple complex serves various religious functions dealing in essential items for the rituals. Rest of the spaces in the outer enclosure, are in the form of covered colonnades or pavilions. This analysis examines only the temple spaces inside the innermost enclosure which are completely enclosed and covered and are more sacred in nature. The spaces within this sacred section of the temple do not have any visual task. The worshippers are required to concentrate their mind only upon God (see Figure 17).
- The chief function of each space within the sacred part of the temple is the ritual of walking barefoot towards the innermost chamber of the temple.

Uniform Illumination Level:

- The main entrance door faces east but does not get any natural light since the spaces around the inner part of the temple are completely covered. There are no other openings in the innermost section of the temple structure (see Figure 17).
- The absence of openings in the structure creates an unbalanced distribution of light.
- Surface reflectance is minimal due to the use of unpolished granite, a low reflectance surface, as a construction material.
- There are no skylights or clerestories in the inner sacred part of the temple, which could have increased the illumination level.

Avoid Direct Glare:

- Due to the absence of direct sunlight inside the temple, baffling daylight view is not required.
- The inner sacred section of the temple is completely covered, which does not let sunlight penetrate inside.
- Low surface reflectance due to use of granite.

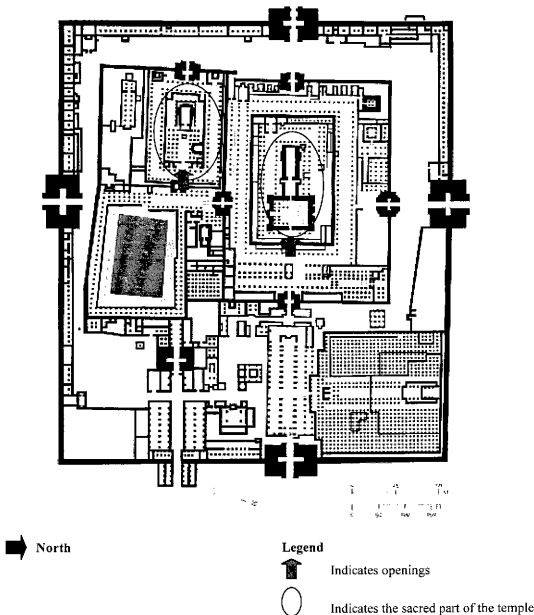


Figure 17: Meenakshi-Sundareshwara Temple, Madurai: Plan showing innermost sanctum
(Source: Stierlin 1998)

Avoid Veiling Reflections:

- Absence of clerestories and skylight helps to avoid veiling reflections.

- Due to the absence of openings in the inner part of the temple, there is no penetration of low angle natural light.

Direct & Diffused Light:

- Absence of openings along with the completely covered space does not allow direct light inside the temple.
- Due to the low reflectance from granite surface and the absence of direct light, there is no indirect light inside the temple.

Avoid Brightness Ratio:

- As mentioned earlier, due to the absence of direct or indirect natural light, brightness ratio does not exist.

Avoid Direct Sunlight:

- There is no direct sunlight inside the temple.
- There is not indirect light inside the temple due to low reflectance granite surfaces and absence of direct light.

Quality of Light:

- There is no direct or indirect light inside the inner sacred part of the temple.

According to this qualitative analysis, it can be said that though the three monuments were built during different time periods, differed in their size and used different building technology, the quality of light in the three temples did not change much due to the strict religious requirements. In spite of the advancement in building technology and the increase in the size of the temples with time, the treatment of light inside the sacred part of the temple remained the same.

Table 4 summarizes and compares the natural lighting system of the three temples according to acceptable lighting design guidelines and their specific criteria (Lechner 1991, 2000; Aitken 1998). The monuments were rated as not fulfilling a given criterion (0), partially fulfilling a given criterion (--), or completely fulfilling a given criterion (+). This ordinal ranking was done to assign numerical figures to the qualitative analysis in order to compare the extent of fulfillment of the lighting design guidelines in the three Hindu temples.

Table 4: Summary of morphological analysis

Design Guidelines	Specific Criteria	SHORE			TANJORE			MADURAI		
Lighting Program	Ritual function of spaces			+			+			+
Uniform illumination Level	Orientation of openings	0					+			+
	High surface reflectance	0			0			0		
	Presence of skylights	0			0			0		
	Uniform light	0			0			0		
Avoid Direct Glare	Baffle daylight view	0					+			+
	Sun protection	0					+			+
	High surface reflectance	0			0			0		
Avoid Veiling Reflection	Limited skylights			+			+			+
	Low angle daylight	0					+			+
Direct & Diffused Light	Controlled daylight	0					+			+
	High surface reflectance	0			0			0		
Avoid Brightness Ratio	Controlled daylight from skylights/openings			+			+			+
Avoid Direct Sunlight	Use indirect light	0			0			0		
	Avoid direct sunlight	0					+			+
Light Quality	Use direct and indirect light		--			--		0		
Total fulfilled (out of 16)		12	1	3	6	1	9	7	0	9

Table 4 summarizes these results and shows that none of the temples fulfill the contemporary lighting design guidelines completely. The Shore temple (700 AD) fulfilled three out of the sixteen design criteria (18%), while the Brihadeshvara temple (1010 AD) fulfilled nine out of the sixteen design criteria (56%). The presence of small and limited number of openings in the Brihadeshvara temple did not allow much light into the temple, making the interior darker than that of the Shore temple. In the case of the Meenakshi-Sundareshwara temple (1660 AD), the inner part of the temple and the areas around it were completely covered to protect it from possible invaders, which in turn did not allow any natural light to enter. As a result, this temple fulfills nine out of

the sixteen design criteria (56%) and the quality of light inside the structure is darker compared to the Shore temple and the Brihadeshvara temple. This is due to the rigid religious requirement, which did not allow the builder to experiment with the quality of light. Thus, though there are differences in the use of lighting techniques in each of the three Hindu temples, on the whole the quality of light inside the structure did not undergo much change. This result strengthens the hypothesis (H_1) of the study, which says that the principles of religion govern the treatment and quality of light in sacred monuments.

The Shore temple (700 AD) is an example of the earliest form of Dravidian architecture when structural building techniques were still at an infant stage. This temple fulfills only three out of the sixteen contemporary lighting design criteria (18%). The Brihadeshvara temple (1010 AD), built on a much grander level using advanced construction technologies (such as post-beam system, corbelling etc), fulfills nine out of the sixteen contemporary lighting design criteria (56%). In the Meenakshi-Sundareshvara temple (1660 AD), the outer parts of the temple became grander while the inner core of the temple shrank in size. This temple form evolved from a necessity to protect itself from the Muslim invaders from northern India. As a result, though this temple is extremely huge, the inner sacred structure of the temple is very small and simple compared to the entire complex. In addition, the fear of a Muslim invasion increased the religious fervor in southern India and the inner sacred part of the temple became more rigid in its design, resulting in extremely dark temple interiors. Therefore, the Meenakshi-Sundareshvara temple does not show an increase in the fulfillment of contemporary lighting design guidelines from that of the temples of 12th century AD. The temple fulfills nine out of the sixteen lighting design criteria, similar to the Brihadeshvara temple. Even when there was no special progress with lighting design from 12th century AD to 17th century AD, it can be concluded that the results are compatible with hypothesis (H_2), which says that accomplishment of light design technology, is a function of time as expressed through building technology and building

size. Due to the unavailability of additional data, these measurements cannot provide an accurate comparison among the three monuments.

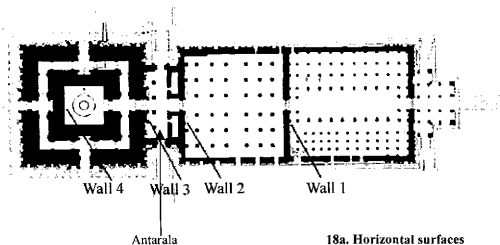
Quantitative Analysis

A quantitative analysis of the Brihadeshvara temple at Tanjore was conducted using Lightscape simulation program. This analysis was conducted only for one of the study samples (the Brihadeshvara temple) due to the lack of documented drawings and detailed information in the case of the other two study samples. The climatic data of the city of Tanjore as shown in Table 2 was used for the quantitative analysis. Lightscape simulation used the Latitude and the Longitude of the city of Tanjore along with the date and time of the year to determine the quality of light in that location.

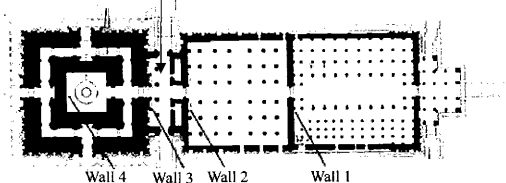
The results of this analysis were drawn in two parts. First, the average illumination values for specific surfaces within the monument were noted and compared relatively to each other. Second, these average values were compared to the Illuminating Engineering Society (IES) standards for lighting design. The simulation results of the Brihadeshvara temple were then compared to the results of its morphological analysis in order to corroborate them.

As explained earlier (see Literature Review, Hindu temple layout and light), a vital aspect of Hindu worship is the actual progression from the outermost spaces (well lighted) to the innermost sacred spaces (completely dark) of a temple. Hence a series of horizontal and vertical surfaces from within each space of the temple was analyzed (see Figure 18). The vertical surfaces, which would directly face a person while walking towards the innermost part of the temple, were chosen. The floors of each space were coded for the horizontal surfaces (see Figure 18a).

The amount of light incident (illumination) on these series of horizontal and vertical surfaces was noted for three time periods. As explained earlier the simulation was run at 7:00 am (sunrise), 12:00 am (high noon) and 17:30 pm (sunset) (see Tables 5 & 6).



18a. Horizontal surfaces



18b. Vertical surfaces

Figure 18: Brihadeshvara Temple, Tanjore: Plans showing the sequence of horizontal and vertical surfaces

Table 5: A comparison of illumination values for a sequence of horizontal surfaces in the Brihadeshvara temple as marked in the Figure 18a

	Time	Floor 1 (lux)	Floor 2 (lux)	Floor 3 (lux)	Floor 4 (lux)
Sunrise	7:00am	268.29	127.36	269.77	0.34
High noon	12:00am	56.89	61.06	381.85	0.35
Sunset	17:30pm	30.84	38.55	287.48	0.53
Average		118.67	75.65	313.03	0.40

Table 6: A comparison of illumination values for a sequence of vertical surfaces in the Brihadeshvara temple as marked in the Figure 18b

	Time	Wall 1 (lux)	Wall 2 (lux)	Wall 3 (lux)	Wall 4 (lux)
Sunrise	7:00am	43.49	4.09	146.6	0.46
High noon	12:00am	46.42	3.54	205.76	0.42
Sunset	17:30pm	25.09	2.18	153.57	0.41
Average		38.33	3.27	168.64	0.43

The findings of the average illumination for the horizontal and vertical surfaces within each space inside the temple show a decrease in the illumination levels as we progress from the outer space towards the innermost space of the temple. This can be seen in the values of Floor 1 through Floor 4 and Wall 1 through Wall 4 in Tables 5 & 6. Floor 3 and Wall 3 show a deviation from this pattern, which is due to the presence of openings on either side of the *antarala* space (see Figure 18). According to historians the presence of a pair of grand stairs and entrances on either side of the *antarala* is unusual in ancient Hindu temple architecture and is a distinct feature of the Brihadeshvara temple (Stierlin 1998).

The average illumination (lux) for each of the horizontal and vertical surfaces was then compared to the Illuminating Engineering Society of North America (IES) standards. As mentioned earlier, the Society established nine broad ranges of *Illuminance Categories* for various types of visual display (tasks). It also recommended ranges of illuminance for specific visual tasks and areas by listing them according to the type of activity (Kaufman 1987). Since the IES standards for sacred architecture refers to churches and synagogues only (see Procedure under Method section), the generic standard illumination values for the categories of 'Public places with dark surroundings' and 'Simple orientation for short temporary visits' were considered appropriate for comparison (see Tables 7 & 8).

Table 7: A comparison of the IES standard illumination values with the average illumination values of the horizontal surfaces in the Brihadeshvara temple.

	Floor 1 (lux)	Floor 2 (lux)	Floor 3 (lux)	Floor 4 (lux)
Average (horizontal surfaces)	118.67	75.65	313.03	0.40
Public space with dark surroundings	30	30	30	30
Short temporary visits	75	75	75	75

Table 8: A comparison of the IES standard illumination values with the average illumination values of the vertical surfaces in the Brihadeshvara temple

	Wall 1 (lux)	Wall 2 (lux)	Wall 3 (lux)	Wall 4 (lux)
Average (vertical surfaces)	38.33	3.27	168.64	0.43
Public space with dark surroundings	30	30	30	30
Short temporary visits	75	75	75	75

The comparison shown in Tables 7 & 8 demonstrates that the average illumination values inside the temple was much lower than the standard illumination level required in this space. The illumination values in the *antarala* are an exception to this pattern due to the presence of entrance doorways on either side of this space. In addition the average illumination on Floor 1 and Wall 1 show a higher illumination level compared to the standard illumination levels. This is due to the presence of a strong focussed light, which hits Floor 1 and Wall 1 at 7:00 am (sunrise) from the east facing entrance doorway (see Tables 5 & 6). The first rays of the sunlight from east are extremely important in Hindu religion since it symbolizes the Sun God. In ancient India the rising Sun was worshipped at dawn before a person started his or her day. Similarly in temples the rising sun is worshipped before beginning the rituals for the residing deity of the temple. The comparative values in Tables 7 & 8 also show that the illumination level inside the temple spaces were not only low but also decreased progressively as one moved towards the innermost sanctum. Though these illumination

levels do not fulfill the standard day light requirements, it is completely compatible with the religious requirements as described in the Literature review section under Hindu temples layout and light. From these observations it can be concluded that strong religious light requirements dictated the quality of light inside the Hindu temples and thus overruled any other considerations. This result supports the hypothesis H_1 of the study, which indicates that the principles of religion govern the treatment and quality of light in sacred monuments.

In addition the results of the quantitative analysis can be compared to the qualitative analysis results for the Brihadeshvara temple at Tanjore for additional validation. The qualitative analysis of the Brihadeshvara temple (1010 AD) showed that this temple used better construction technologies compared to the earlier Shore temple (700 AD). Unlike the Shore temple, the Brihadeshvara temple started using windows as openings to get light inside the structure. But due to the very small and limited number of windows, the light quality inside the temple remained extremely dark. The fact that this temple fulfills only 56% of the contemporary lighting design criteria shows that the lighting design of the Brihadeshvara temple followed the religious lighting requirements and did not take any other factor into consideration. This finding can be corroborated by the findings of the quantitative analysis, which showed a strong influence of religion on the lighting design of the Brihadeshvara temple.

SUMMARY AND CONCLUSION

This paper discusses the phenomenon of natural light that becomes the holy light in sacred architecture. Throughout time, religious buildings used natural lighting systems in the form of skylights, clerestories and window openings. Natural light was manipulated inside the buildings through materials, colors and building elements to achieve the desired quality of light that is dictated by religious rituals and symbols. In pursuing this investigation the study addressed three major objectives. First, to understand the significance of religion in the treatment of light in sacred monuments around the world. Second, to understand the methods used to achieve the desired light quality in the ancient south Indian Hindu temples. Third, to add to the existing body of knowledge in the field of study of ancient south Indian Hindu temples. Following these objectives the study developed two hypotheses on the basis of a literature review. The first hypothesis (H_1) examined the link between religion and the accomplished quality of light in sacred buildings by showing that *the principles of religion govern the quality of light in sacred monuments*. The second hypothesis (H_2) highlighted the advancement of building technology (e.g. materials, structural systems etc.) throughout time along with changes in building size. Thus, H_2 suggests that *accomplishment of light design technology (H_1) is a function of time as expressed through building technology and building size*.

To test these hypotheses this paper studied the natural light systems in three Hindu temples built in the southern state of Tamilnadu in India. These three temple are the Shore temple built at Mahabalipuram by the Pallava dynasty (700 AD); the Brihadeshvara temple built at Tanjore by the Chola dynasty (1010 AD); and the Meenakshi-Sundareshwara temple built at Madurai by the Nayaka rulers (1660 AD). The study was conducted using multi-method analyses that included a qualitative analysis using accepted lighting design guidelines, and a quantitative analysis in the form of computerized day light simulations.

The morphological analysis of the three Hindu temples showed that along with the passage of time, there was a steady development in building technology and an increase in the size of the temples. As a result there was progress in the development of lighting design from the 8th century AD to the 11th century AD. But from the 12th century AD to the 17th century AD there was no special progress seen in the lighting design of Hindu temples due to the political developments during that period, which forced the fortification of the temple complex and the maintenance of a small sanctuary in the temple. This analysis also showed that the light inside the Hindu temples became darker in quality from 700 AD (Shore temple) to 1010 AD (Brihadeshvara temple), and even darker in 1660 AD (Meenakshi-Sundareshwara temple). This finding shows the rigidity of the religious principles dictating the quality light in the southern Hindu temples, with more light at the entrance progressing towards complete darkness in the sanctuary. In later years due to an increasing number of foreign invasions into India, the Hindu temple plans started to become more enclosed, which in turn affected the lighting design resulting in extremely dark temple interiors. These results support the first hypothesis (H_1) of the study, that the principles of religion govern the treatment and quality of light in sacred monuments. The qualitative analysis is also compatible with hypothesis (H_2), which says that accomplishment of light design technology, is a function of time as expressed through building technology and building size.

The quantitative analysis utilized Lightscape, which is computerized light simulation software. The simulations were run only on the Brihadeshvara temple due to the lack of accurate data on the other two temples. The results of the quantitative analysis showed a decrease in the illumination levels from the outer spaces towards the innermost part of this temple. It also showed that the average illumination values inside the temple were much lower than the contemporary standard IES (Illuminating Engineering Society) illumination level required in such space. Comparing these results with the qualitative analysis, regarding the quality of light in the Brihadeshvara temple, supported hypothesis H_1 , that there is a strong influence of religion on the lighting design of the Brihadeshvara temple. Since the study conducted a computerized light

simulation for only one temple, further use of Lightscape simulations should be conducted for the other two temples upon availability of information¹⁷. In addition, it is recommended that the research will extend to include other regions within India in order to test the study's hypotheses for different styles of Hindu temple architecture and different quality of light.

The results of the qualitative and the quantitative analyses show that though there are differences in the building size and techniques in each of the three Hindu temples, on the whole the quality of light inside the structure did not undergo much change. The findings show that there was a significant progress in the technology of lighting design from the 8th century AD to the 11th century AD. However, due to the changes in the political scenario from the 12th century AD, there was no further progress in this aspect of south Indian temple design.

It can be concluded that the results of this study support the paper's hypotheses and follow the Hindu religious requirement for light. As mentioned earlier in the study, the ritual of worship which included focussing one's mind completely on God, was extremely important in southern Hindu temples of India. In order to achieve this the Hindu temples were designed to attune the five human senses completely towards worship. These five senses are the sense of vision, the sense of hearing, the sense of touch, the sense of smell and the sense of taste. This study addressed the sense of vision in order to understand the religious significance of light and dark in the south Indian Hindu temples. The temple interiors were designed to be dark so the human eye was not distracted by the material world, which in turn let the mind enter the spiritual world of God. The significance of this spiritual experience played a key role in the design of Hindu temples. As seen in study's temples, natural light in a progressive light quality from brightness to darkness was introduced in a controlled way to the temples. Furthermore, the reduced level of light quality in the southern Hindu temples of India also contributes to the thermal comfort in these buildings. Since the south Indian

¹⁷ It is necessary to visit the sites of the temples to record and document the structure.

climate is extremely hot and humid, the Hindu temples were designed with thick walls and small windows that maintain cool and dry conditions for better thermal comfort. The Hindu worshippers are provided with physically comfortable conditions in order to achieve the goal of focussing one's mind on God.

Finally it should be noted that due to lack of information, the study could not include examples of Hindu temple with artificial lighting system. However, it is suggested that a further investigation of comparing examples of Hindu temples with natural lighting systems to that of modern Hindu temples with artificial lighting systems should be undertaken. This comparison will test this study's hypothesis showing if and how contemporary techniques accommodate the religious requirements of light in these sacred monuments.

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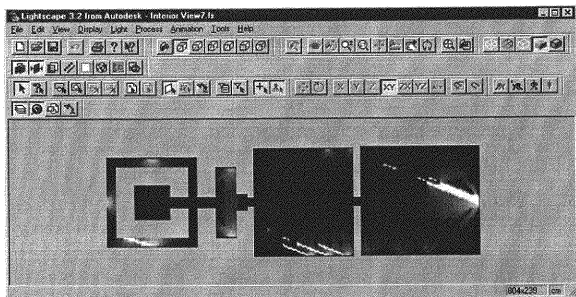
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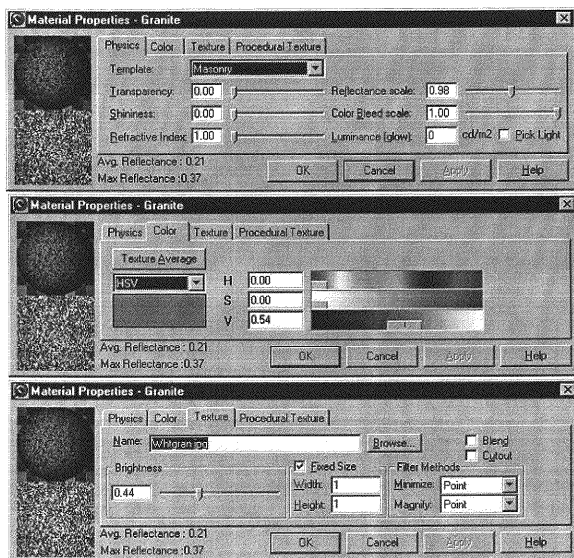
APPENDIX I

I-a



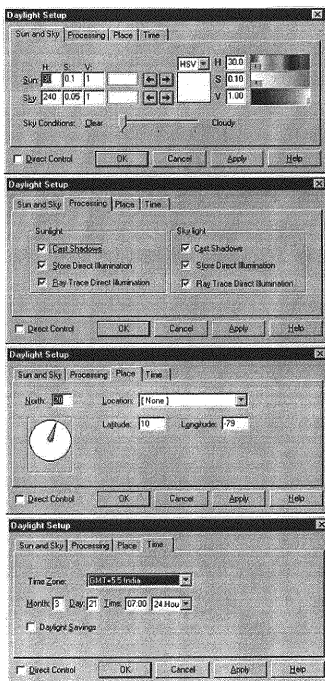
Sample of the main window in Lightscape program.

I-b



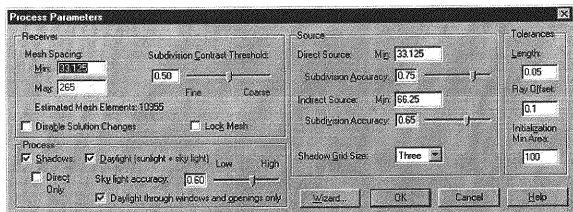
Sample of the Material Properties window in Lightscape program.

I-c



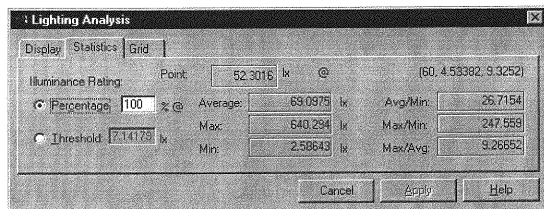
Sample of the Daylight Setup window in Lightscape program.

I-d



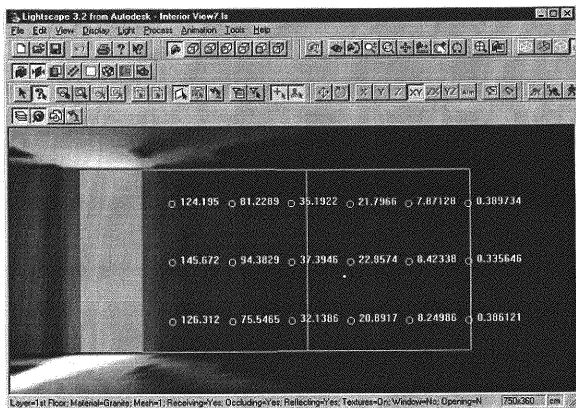
Sample of the Process Parameter window in Lightscape program.

I-e



Sample of the Lighting Analysis window in Lightscape program.

I-f



Sample showing the illumination values on a surface in a grid format during the Lighting Analysis in Lightscape program.

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